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MEMOIRS
OF
THE GEOLOGICAL SURVEY OF INDIA

THE NEW YORK
ACADEMY OF SCIENCES

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA

VOLUME XXXVI

Published by Order of the Government of India

CALCUTTA :

SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY OF INDIA,
27, CHOWRINGHEE ROAD

LONDON: MESSRS. KEGAN PAUL, TRENCH, TRÜBNER & CO
BERLIN: MESSRS. FRIEDLÄNDER UND SOHN.

1904-1912.

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Deputy Superintendent, Geological Survey of India.

INTRODUCTION.

Our knowledge of the geology of that part of the higher Himálayan ranges which lies to the west of the Nepál frontier has been derived chiefly from the examination of three distinct areas, namely, the Kumaon and Garhwál Himálayas on the east, Kashmir with Ladákh on the west, and Spiti, lying between these two. This three-fold partitioning is not due to any geological or stratigraphical peculiarities of the respective subdivisions, but merely to their physical conformation, each area being accessible from one or more routes which are more or less central to it, but do not give access to the others, while the passage from the central area, Spiti, to those lying on either side is a matter involving considerable time and difficulty. The inevitable consequence of these conditions is a lack of homogeneity in the geological results, a lack still further enhanced by the fact that, except with regard to the lower trias, no two areas had until quite recently been examined in any detail, nor, with a few exceptions, even visited, by one and the same observer.

Naturally, it is to the central, or Spiti, area that we look for the means of correlating what knowledge we have of the neighbouring divisions; but this is a matter of no small difficulty. The eastern

area, indeed, has been described in considerable detail, first by General Strachey,¹ the pioneer of Himálayan stratigraphical geology, and subsequently by Mr. Griesbach;² again in 1891, parts of the same area were visited by Messrs. Griesbach and Middlemiss, accompanied by Professor Diener, whose researches³ have added largely to our knowledge of the characters and correlation of the Himálayan trias. Still further additions have been made during the last few years by the work of Messrs. La Touche and Smith and Drs. Noetling, Walker and von Krafft. So far, then, as this area is concerned, we have a considerable amount of material available for our purpose. Unfortunately the same cannot be said of the western, or Kashmir, area. Practically the whole knowledge that we possess is derived from Mr. Lydekker's work on the geology of Kashmir.⁴ The detailed study of so large an area would necessarily involve many years' labour, and Mr. Lydekker found it impracticable to attempt any minute subdivision of the sedimentary rocks. He, therefore, divided the whole stratigraphical series into three systems, the tertiary, the Zánkár, and the Panjál, in the last of which he included the cambrian and silurian systems, while the Zánkár represents all European systems from the base of the carboniferous to the top of the cretaceous. In each of the two latter systems he recognised certain subdivisions corresponding to the various series of Spiti, as described under local names by Stoliczka. It is thus possible to make some attempt to correlate roughly these two adjoining areas, but the general absence of detailed descriptions of sections or of fossiliferous horizons renders any accurate correlation impossible, nor can this be attempted until the stratigraphy of Kashmir has been studied in greater detail.

The fact that a portion of Spiti was visited by Mr. Griesbach on the completion of his work in the Kumaon and Garhwál Himálayas,

¹ Quart. Journ. Geol. Soc., VII (1851), p. 292.

² Memoirs, G. S. I., vol. XXIII.

³ Denkschrift. d. k. Akad. d. Wiss., Wien, 1895.

⁴ Memoirs, G. S. I., vol. XXII.

and his account of the geology of that part traversed by him,¹ render a correlation of the central with the eastern area a comparatively simple matter, and one which has been still further facilitated by the numerous detailed sections to be found in his memoir, as well as by his employment of European nomenclature in his description of the corresponding rock-systems of the Himálayas.

In rapid or preliminary traverses of a previously unexplored area where, owing to paucity of fossils or to other causes, the various sedimentary formations cannot be definitely referred to known European equivalents, the adoption of local names for the more prominent lithological units is no doubt advisable and even necessary, but when the survey has advanced to a further stage, and sufficient palæontological evidence can be adduced to determine the approximate homotaxial relations of the more important subdivisions, the multiplication of terms leads merely to confusion. In the present memoir this has been kept in view, and the various systems have, so far as possible, been designated by the names of their European equivalents; a few terms, however, such as "Spiti Shales," and "Giumal Sandstone," which have now become historical and have been universally applied throughout the Himálayas, have been retained; while others, such as "Pára limestone," which have no special appropriateness, and may even include portions of two different systems, have been discarded. This applies especially to Mr. Lydekker's terms "Zánskár" and "Panjál," under each of which names he included, as already stated, more than one European system, and where parts of the area surveyed by him have been touched on in the following pages, his terminology has not been employed.

The geological map accompanying the present memoir is the joint work of the late Dr. von Krafft and the present writer, and is based on the "Atlas of

¹ Memoirs, G. S. I., vol. XXIII, pp. 206—223; Records, G. S. I., vol. XXII, pp. 158—167.

India" (1 inch = 4 miles). All boundaries were carefully followed as far as possible, but, owing to the small scale and inaccuracies of the topographical map, it has frequently been found impossible to reproduce the smaller structural details. In addition to this, owing both to physical and political difficulties, certain parts of the range separating Spiti from Western Tibet were inaccessible, and geological boundaries could therefore be drawn only approximately. This is especially the case in that part of To-tzo (Western Tibet) which lies to the east of the Spiti river, and which could be only rapidly and surreptitiously traversed; for the local inhabitants, although as a rule exceedingly friendly and not disposed to place any serious obstacles in the way of travellers, have during the last few years jealously guarded their frontier, in consequence of a recent attempt on the part of a tactless and irresponsible traveller to force his way in the teeth of all opposition into the more easterly parts of their country.

CHAPTER I.

PREVIOUS ACCOUNTS OF THE GEOLOGY OF SPITI.

Although Spiti had been visited by geologists at various times during the past century, no detailed systematic survey had been made, and in 1898 it was decided that a more careful study of the whole area should be undertaken. For this purpose the present writer was deputed to Spiti in the summer of that year; the work was continued by him, accompanied by the late Dr. von Krafft, in 1899, and by the present writer again during the summer of 1901.

The work carried out during the above three seasons, while claiming no pretensions to detail, has, however, been brought up as far as possible to an uniform degree of completeness, sufficient, it is hoped, should occasion ever arise, to facilitate an intimate study of horizons and sections.

Of the various papers relating to Spiti and neighbouring areas the following are of chief importance:—

STOLICZKA (*F.*).—Geological sections across the Himálayan Mountains.

(Memoirs, G. S. I., vol. V (1866), art. i, pp. 1—154.)

STOLICZKA (*F.*).—Summary of geological observations during a visit to the provinces—Rupshu, Karnág, South Ladákh, Suroo and Drás—of Western Tibet, 1865.

(Memoirs, G. S. I., vol. V (1866), p. 337.)

MALLET (*F. R.*).—On the Gypsum of Lower Spiti.

(Memoirs, G. S. I., vol. V (1866), art. ii, pp. 153—172.)

MCMAHON (*GEN. C. A.*).—Notes of a tour through Hangrang and Spiti.

(Records, G. S. I., vol. XII, pp. 57—69.)

OLDHAM (*R. D.*).—Notes on the Geology of the North-West Himá-
layas.

(Records, G. S. I., vol. XXI, pp. 130—143, and
pp. 149—159.)

LYDEKKER (*R.*).—Geology of Kashmir.

(Memoirs, G. S. I., vol. XXII.)

GRIESBACH (*C. L.*).—Geological notes.

(Records, G. S. I., vol. XXII, pp. 158—167.)

GRIESBACH (*C. L.*).—Geology of the Central Himálayas.

(Memoirs, G. S. I., vol. XXIII.)

In addition to the above, progress reports by the late Dr. von Krafft and by the present writer were published, during the course of the work, in the General Reports, Geological Survey of India, for the years 1898-1899, 1899-1900, 1901-1902.

Of the above papers, those of McMahon and Oldham relate chiefly to the vexed question of the correlation of the
McMAHON: OLDHAM. beds of Spiti with the pre-tertiary formations of the outer Himálayas; these will be discussed below (*vide* chap. VIII).

The paper by Mallet is confined chiefly to mineralogical questions, including that of the origin of the gypsum,¹ and
MALLET. does not deal with stratigraphy.

Of the remaining papers, those of Stoliczka embody the first systematic account of the geology of Spiti.
STOLICZKA. Although, owing to the short duration of his visit, this account necessarily lacks completeness and detail, yet the majority of his general conclusions have been borne out by the recent, more detailed work.

He divided the whole stratigraphical sequence into the following ten series:—

Chikkim beds	.	.	.	.	.	.	.	Cretaceous.
Giumal sandstone	.	.	.	.	.	.	.	Upper oolite.
Spiti shales	.	.	.	.	.	.	.	Middle oolite.
Upper Tagling limestone	.	.	.	.	.	.	.	Middle lias.
Lower " "	.	.	.	.	.	.	.	Lower "

¹ *Vide infra*, p. 101.

Pára limestone	.	.	.	.	.	.	Rhætic.
Lilang series	.	.	.	.	.	.	Upper trias.
Kuling series	.	.	.	.	.	.	Carboniferous.
Muth series	.	.	.	.	.	.	Upper silurian.
Bhabe series	.	.	.	.	.	.	Lower „

Each of the above series will be dealt with in detail in the chapters relating to the systems that they represent.

Mr. Griesbach's chief object in visiting Spiti was to endeavour to remove certain discrepancies existing between Stoliczka's account of the stratigraphy of Spiti and the conditions observed by him in the Kumaon and Garhwál Himálayas. His short account, although based on a somewhat rapid traverse, constitutes a distinct advance in our knowledge of the geology of Spiti.

As will be seen from his memoir, the chief points on which he differed from Stoliczka, were—

- (1) the age of the Muth quartzite (8)¹ and underlying beds ;
- (2) the vertical extent of the carboniferous system ;
- (3) the age of Stoliczka's " Kuling series " ;
- (4) the presence or absence of beds of lower triassic age.

With regard to the first point, subsequent work has shown that Stoliczka was correct in regarding the beds underlying the Muth quartzite as of silurian age, but no direct evidence as to the age of the quartzite itself has yet been found.

With regard to the carboniferous system, Mr. Griesbach has shown that Stoliczka had erroneously included in it the " Productus shales," now known to be of permian age : these Stoliczka named the " Kuling shales," and included with them certain dark limestones found at Kuling and at Muth, and which are, in part at least, of carboniferous age.

Mr. Griesbach was also the first to prove the existence of the lower trias in Spiti, Stoliczka having failed to notice it, though it appears that he subsequently came to the conclusion that beds of that age were to be found in the Himálayas.²

¹ This is the number employed by Mr. Griesbach in his list of formations.

² Memoirs, G. S. I., vol. V, p. 345.

CHAPTER II.

CAMBRIAN SYSTEM

A glance at the map will show that the Spiti valley has a general N. W.—S. E. trend, to which the strike of the sedimentary rocks to a great extent conforms. With this strike is combined a northerly dip: hence the outcrops of the various systems form a series of bands, the oldest lying to the south.

The most southerly band constitutes a part of the oldest known sedimentary system in the Western Himálayas, and to a large extent forms the great snowy range separating Spiti from Kulu and Bashahr. It has been designated by a variety of names, the best known of which are "Azoic" (Strachey), "Bhabeh series" (Stoliczka) and "Haimanta" (Griesbach).

Before passing on to a description of this system, as seen in Spiti, *Metamorphic rocks.* it is necessary to notice certain beds which are Gneiss. said to underlie it in other parts of the Himálayas. These are Mr. Griesbach's "vaikrita" system, and the so-called "central gneiss." The latter rock has been found by General McMahon to be in reality a gneissose granite: it is seen throughout the Suttlej valley from Wangtu to Shipki, and again along the Spiti river, and at Changrizang on the lower Pará river, one of Stoliczka's type-localities, where it is found intrusive both in cambrian and permian beds.

The other series described by Mr. Griesbach from the Niti area, as Schists of Wangar of probably pre-cambrian age, is the vaikrita system, composed of schists, talcose rocks, phyllites and gneiss. From near Wangtu bridge on the Suttlej to within a short distance of the Bhabeh Pass, the road passes over a complex series of mica-gneisses, kyanite-schists and garnetiferous mica-schists, with basic igneous rocks and much intrusive granite (central gneiss). The

schists might possibly be regarded as the equivalents of Mr. Griesbach's
of the Sutelj vaikrita system. Similar schists are, however,
valley. found in the Sutelj valley between Spueh and
Hango, and again on the left side of the Spiti river below Chango. In
the latter localities the kyanite-schists and garnetiferous mica-schists
are found to pass horizontally into less altered phyllites and clay-slates
belonging to the cambrian system and corresponding to Mr. Griesbach's
middle haimantas. Similarly, highly altered staurolite and kyanite
schists are found between Asrang and Pangi, where the intrusive biotite
granite is found in contact with the cambrian slates. There is therefore
no reason to suppose that the schists of the Wangar valley represent the
vaikrita system, for they also are probably only altered representatives
of the cambrian slates, while the more acid gneisses, which occur among
them, may very possibly have been produced by the alteration of the
fine grits and quartzites of the same system.¹

"Haimanta" sys-
tem of Griesbach.

The haimanta system has been subdivided by
Mr. Griesbach into three groups—

- (c) *upper haimanta*—consisting of "quartz shales and slates"
(= "red quartz shales");
- (b) *middle haimanta*—"shales and silky phyllites, with great
thickness of quartzites";
- (a) *lower haimanta*—"quartzite, generally purple, with great
thickness of conglomerate."²

Of the above subdivisions, the upper and middle can be readily
recognised in all the older palæozoic sections in Spiti and Bashahr, but
the lowest, characterised by the presence of conglomerates, has not been
found. Mr. Griesbach states,³ however, that he found a "conglomerate,
or rather, boulder-bed" among the haimantas of Spiti. In spite of

¹ It is probable that not only in this area, but also in other parts of the
Himālayas, many of the rocks which have hitherto been relegated to the limbo of
the "crystalline schists" are in reality merely altered sedimentary beds.

² Memoirs, G. S. I, vol. XXIII, p. 51.

³ *Ibidem*, p. 210.

careful search, neither the late Dr. von Krafft nor the present writer succeeded in finding this among the lowest beds, but a conglomerate, very similar to that described by Mr. Griesbach, was found overlying the cambrian beds, and invariably defining the boundary between them and the silurian rocks. Numerous blocks of the conglomerate are found along the route traversed by Mr. Griesbach, and since he states¹ that he did not examine the beds in any detail, it is possible that on meeting with a rock bearing so close a resemblance to the lower haimanta conglomerate of Niti, he came to the natural conclusion that it was the same. A fuller description of this rock will be found below (see p. 22).

The oldest sedimentary rocks, therefore, with which we have to deal are the slates and quartzites belonging to Oldest sedimentary rocks of Spiti. Mr. Griesbach's middle haimantas. They consist chiefly of soft, ferruginous clay slates,—thinly foliated and often crushed and micaceous (phyllite)—interbedded with bands of grey and purple quartzite. Thin beds of grit ranging from a few inches to a foot in thickness are not uncommon, especially near the upper boundary of the series. These rocks extend from the north-western end of Spiti, throughout the whole length of the chain of snowy peaks separating Spiti from Kulu and the Wangar valley, into the valleys of the Teti (Taite) and Thanam rivers in Bashahr, continuing eastwards from Sungnam, and forming most of the hills on either side of the Sutlej and Spiti rivers below Lio and Chango in Kanaur. At either end, they appear to run on in the direction of Garhwál and Kumaon on the south-east and of Lahaul on the north-west, and extend for many miles down the valley of the Sutlej, below its confluence with the Spiti river. Along their southern boundary they are found, in Spiti and Bashahr, in contact with great masses of intrusive granite. Near the line of junction, they have been highly altered, chiefly into garnetiferous mica schist, biotite schist, biotite-kyanite schist and biotite-staurolite schist.

¹ *Op. cit.*, p. 120.

In the valley of the Chandra river, between Kulu and Spiti, the commonest product of alteration is a dark biotite schist, composed of biotite, quartz, felspar (orthoclase, albite and micropertthite), with some rutile and zircon.

In the valley of the Sutelj, the products of contact-metamorphism are similar to those in the Chandra valley, but to the other component minerals are added kyanite and staurolite, the former occurring in large crystals, often of a beautiful blue colour, which has led to their being mistaken for sapphires.

Biotite-kyanite schist and biotite-staurolite schist.

Fine specimens of this biotite-kyanite schist are found between Naku and Chango on the left side of the lower Spiti river, and also on the left side of the Kozhang river on the old road from Pangi to Asrang. At the latter locality, staurolite occurs in great quantity, locally replacing most of the kyanite, the rock thus becoming a biotite-staurolite-kyanite schist: it contains also quartz, orthoclase, albite, zircon and large quantities of rutile; an iron ore, probably ilmenite, is found in small grains scattered through the staurolite, to which it appears to be entirely confined.

In the neighbourhood of Lio, in the valley of the Lipak river, the effects both of contact- and of dynamo-metamorphism are very pronounced, and on the right bank of the river, at about two miles above its junction with the Sutelj, the lower slates and quartzites contain the only rock, which, having regard to its appearance and position, could be supposed to belong to Mr. Griesbach's lower haimanta conglomerates. The rock is a conglomerate forming a bed of varying thickness, and composed of more or less rounded and lenticular fragments of white quartz, scattered through a matrix of fine-grained biotite schist. The band is usually ten or twelve feet in thickness, and in places contains the white pebbles throughout its whole extent; in other places, however, only narrow strings of pebbles, separated by bands of schist, run both parallel and obliquely to the original direction of stratification of the rock. When first seen in the bed of the river, the conglomerate was taken for the one which occurs throughout Spiti at the base of the silurian system

subsequent examination showed, however, that it did not immediately underlie that system, from which it is separated by a great fault, but occurred low down among the middle haimanta slates and quartzites, and when followed for a short distance, it was found to pass gradually into a great mass of white quartz, which occurs at the water's edge on the right bank of the river. An examination of this exposure at once showed that the rock was an autoclastic conglomerate, formed by the crushing of veins and narrow strings of quartz, which are seen running out from the main mass: these become broken up into fragments and eventually take the form of strings of pebbles, sometimes coalescing again into veins, at others forming bands of pseudo-conglomerate. Further evidence as to the true character of the rock was found on the opposite side of the stream, where an old basic dyke is seen, part of which has been similarly converted into an autoclastic conglomerate.

No fossils have been found in Spiti or in Bashahr, in this series of
 Age of the slates slates, quartzites and grits, and there is, there-
 and quartzites. fore, no direct evidence as to its age. By
 Stoliczka it was included in, and constituted the greater part of, his
 "Bhabeh series," which he classed as "lower silurian." There can
 be little doubt that, in common with most continental and many
 English geologists of his time,¹ he employed the term "silurian" in its
 widest sense, to include all pre-devonian fossiliferous systems then
 known. His "lower silurian" would therefore include the cambrian
 system, and his "upper silurian" the silurian system of modern
 English geologists.²

The "Bhabeh series" was subsequently identified by Mr. Griesbach with his haimanta system, which he regarded as of cambrian, and probably also in part of pre-cambrian, age.

¹ And also some prominent continental geologists of the present day; see de Lapparent, *Traité de Géologie*, 4th edition.

² In the present memoir the cambrian is retained, in conformity with modern English usage, as a separate system. In the silurian are included all the beds between the cambrian and devonian systems, i.e., the "ordovician" and "silurian" (lower and upper silurian), respectively.

The total thickness of the series cannot be even approximately determined, for although extending for many miles in the valleys of the Thanam, Pin and Parahio rivers, with a more or less constant northerly dip, the beds have undergone repeated folding, and their apparent thickness is thus very great, especially in the Pin and Thanam valleys, where the arches of the anticlines have been completely removed by denudation. In the Parahio valley, however, remains of numerous folds can still be seen (see Pl. I, fig. 2), thus proving that the enormous thickness is only apparent; it is probable, however, that an estimate of between two and three thousand feet will not err on the side of excess.

The overlying beds which presumably comprise Mr. Griesbach's upper haimantas, consist of a series of black, Red and black slates. purple and grey slates, with grey, green, and red quartzites. The lower part of the series is chiefly argillaceous, and the upper mainly siliceous. The grey and purple slates are highly ferruginous, and contain large quantities of hæmatite and limonite, pseudomorphous after pyrite; the weathered surfaces of the rock are consequently completely coated with orange and bright red films of ochre, and the outcrop stands out as a brilliant red band running through the darker slates, and presumably constituting Mr. Griesbach's horizon of "red quartz shales." Among the argillaceous beds are bands of an intensely black, carbonaceous shale, resembling the carbonaceous shales of Simla.

The red and black beds form an unmistakable and very constant horizon, well seen in the Parahio and upper Pin valleys of Spiti and the Thanam (locally called Samandar) river in Bashahr, where it has a thickness of not less than 1,000 feet.

In the Parahio valley the upper siliceous beds pass up gradually into a series of grey and green micaceous quartzites and thinly foliated slates and shales, with narrow bands of light-grey dolomite.

The slates, which are usually dark-blue or black, vary in composition

from a soft, argillaceous rock to a hard, siliceous variety with much mica. They are very finely laminated and much crushed, and the direction of foliation being usually oblique to the bedding, the rock frequently resembles a needle shale. The slates are interbedded with great regularity with grey, yellow or whitish quartzites, which are almost invariably capped by a narrow band of either calcareous quartzite or dolomitic limestone only a few inches in thickness. The limestone, which is grey on fresh fracture, weathers to a pinkish or brownish red, and is again overlain by slates, which are at first argillaceous but gradually become more and more siliceous, till they pass up again into quartzites; this alternation continues with great regularity for many hundred feet. Towards the top of the series the argillaceous beds give place to light-coloured siliceous slates and thin-bedded, flaggy quartzites with bands of red and pink dolomite, which latter gradually increases in frequency and thickness, till it becomes the predominant rock.

These beds constitute the oldest fossiliferous series hitherto found in Spiti. The fossils, which consist chiefly of *Lingulella* and trilobites, are most numerous in the argillaceous beds, but the narrow bands of limestone, and, in places, the flaggy quartzites, are also fossiliferous.

The most complete section is seen in the valley of the Parahio, where the following sequence of rocks forms the steep hills on the left bank of the river, above Maopo E. G.¹—

19. Conglomerate.		
18. Quartzite and siliceous shale	about	50 feet.
17. Grey dolomite, weathering brownish-red	"	20 "
16. Flaggy sandstone, quartzite and siliceous slate	"	40 "
15. Grey dolomite, weathering brownish-red	"	30 "
14. Siliceous slates, with grey quartzite bands and thin beds of pink dolomite (slates chiefly grey and green, but weather pink)	"	250 "
13. Dark siliceous slates, with a few fragmentary trilobites	"	10 "
Carried over		400 feet.

¹ E. G.=Encamping ground.

Brought forward about 400 feet.		
12. Siliceous slates and flaggy quartzite	30	”
11. Siliceous and argillaceous slates, with trilobites	6	”
10. Grey slaty quartzite, capped by dolomite (6")	50	”
9. Slates, siliceous above and argillaceous below, with trilobites	30	”
8. Dark-grey quartzite	60	”
7. Pink shaly dolomitic limestone, with trilobites	12	”
6. Calcareous quartzite, with <i>Lingulella</i> and trilobites, underlain by narrow band of fossiliferous limestone (2") and argillaceous slates, with many trilobites	10	”
5. Grey micaceous quartzite, with thin bands ($\frac{1}{4}$ " to 2") of mica schist	150	”
4. Slates, alternating with narrow bands ($\frac{1}{2}$ " to 4") of grey limestone, with <i>Lingulella</i> and trilobites	10	”
3. Slate, chiefly siliceous, and quartzite	150	”
2. Dark slate, with trilobites	30	”
1. Red and green slaty quartzites, with <i>Lingulella</i> and trilobites in the uppermost bands	250	”
		<hr/> 1,188 feet.

The thickness of the individual sub-divisions as given in the above list is in most cases merely approximate, for the whole series is disturbed by faults and no really consecutive section can be found.

The lowest horizon at which fossils were found occurs near the top of the reddish quartzites (No. 1), which overlie the bright red slate series. The rock from which they were obtained is a hard, calcareous and micaceous quartzite, containing numerous valves of a small brachiopod resembling *Lingulella*; with these are associated fragments of the head-shields of a trilobite, too badly preserved, however, for even generic determination. Above this are flaggy quartzites, in thin beds, the surfaces of which are covered with impressions resembling those ascribed by Nathorst to the tracks of invertebrate animals.¹ The same markings are common in, and characteristic of, these quartzites throughout Spiti.

¹ Kong. Svensk. Vet. Akad. Handlingar; Bd. XVIII, Bd. XXI.

The next horizon from which fossils have been obtained in any appreciable number is bed No. 2 ("dark slate with trilobites"). In this bed and in No. 4, numerous remains (chiefly head-shields) of trilobites occur; they are unfortunately all poorly preserved.

Bed No. 6 has yielded a large number of specimens, many of which are in a very fair state of preservation; they consist chiefly of species of *Ptychoparia*, *Corda* and allied genera.

In bed No. 9, *Ptychoparia* is still found, and with it large numbers of fragments of *Olenus* sp., and *Dikelocephalus* sp.

The highest zone in which determinable fossils have been found is bed No. 13: they are, however, not numerous. *Ptychoparia* is very rare, being almost entirely replaced by species of *Olenus*.

Collections were made from all the above horizons, but have been sent to England for description. It is therefore at present only possible to give the above generic determinations, founded on a cursory examination made by the present writer before the despatch of the materials to England. These data, though meagre, are yet sufficient to warrant the inference that the fossiliferous beds are of upper—possibly also of middle—Cambrian age.

As already stated, the series attains its greatest development in the valley of the Parahio, where its total thickness is nearly 1,200 feet. In the section described, the uppermost dolomite has undergone considerable alteration and contains no determinable fossils, though a few fragments of head-shields of trilobites have been found in it, but the lithological continuity of the series up to the base of the conglomerate (19) renders it desirable, in the absence of proof to the contrary, to place the whole in one and the same system. In addition to this, a distinct change in the character of

the deposits, accompanied by a marked unconformity, occurs at the base of the conglomerate, and in view of the not infrequent coincidence of a palæontological with a lithological break, the upper quartzites, slates and dolomites have been included with the underlying fossiliferous beds, in the upper

cambrian, and the overlying conglomerate adopted as the base of the silurian system.

This lithological break, with the accompanying unconformity, is constant throughout Spiti and Bashahr. The section above described is the most complete yet found, and the unconformity between the shales and quartzites (bed 18) and the overlying conglomerate (bed 19), although distinct, is not pronounced, but a few miles further to the south, on the right side of the Parahio and in the high range between that river and the Pin valley, as also in the Thanam river in Bashahr, ample evidence of the break exists; the conglomerate is found resting on a denuded surface of the cambrian rocks, the greater part of the fossiliferous beds having in some instances been removed prior to its deposition.

To the west and north the upper cambrian system is found chiefly in the great snowy range separating Spiti from the Kulu valley, and is to a large extent inaccessible, but wherever seen, similar denudation of the older rocks is found to have taken place before the deposition of the conglomerate.

Even before the close of the cambrian period local disturbance appears to have set in. Evidence of this is found in the great snowy range separating Spiti from the Kulu valley, and is to a large extent inaccessible, but wherever seen, similar denudation of the older rocks is found to have taken place before the deposition of the conglomerate.

Evidences of local disturbance during upper cambrian times.

appears to have set in. Evidence of this is found on the right bank of the Parahio, above Changnu E. G., where the trilobite-bearing slates are overlain by the following series of beds :—

19. Conglomerate.

Unconformity.

- 18. Dark siliceous and carbonaceous slates.
- 17. Dolomitic limestone, passing horizontally into coarse conglomerate.
- 16. Red siliceous shale.
- 15. Dolomitic limestone.
- 14. { Pink and red limestone.
- { Grey limestone with shell remains.

It will be seen that this section, which occurs at about a mile to the south-east of the river, corresponds to the section already described from the left bank, but between these two localities a striking change occurs in the upper limestone (No. 17) which passes horizontally into a great mass of coarse conglomerate, composed of large blocks of the

same limestone in a calcareous matrix. Mixed with the limestone blocks are a few pebbles and angular fragments of quartzite, resembling that of the underlying beds. The conglomerate occurs on both sides of the river, but is particularly well seen above the right bank, where it forms a cliff above 250 feet in height, but rapidly dwindles away on either side and passes horizontally into the normal dolomite.

The main mass of the conglomerate consists of very large blocks, often as much as a ton in weight, of the grey limestone and of the dolomite found in the adjacent sections, but near the base of the cliff it is composed of large boulders—many being of quartzite—from six inches to a foot in diameter, embedded in a siliceous and slaty matrix. This rests on an eroded surface of upper cambrian slates and quartzites (Pl. VI). It would appear, therefore, that towards the close of the cambrian period disturbances had begun to take place locally, resulting in contemporaneous erosion. The original conditions, however, seem to have been soon restored, for both the conglomerate and the dolomite are overlain by the same band of dark slates (No. 18), above which occurs the great cambro-silurian unconformity, which extends throughout Spiti and Bashahr.

No further evidence of local disturbance during upper cambrian times has been observed, for the highest beds of that system have been found only in the Parahio valley. Thus, on the high range to the west of Muth in the Pin valley and a few miles south-east of the Parahio, the lower silurian conglomerate rests in places on a small thickness of the lower dolomite (bed 15), and in places on the underlying slates, while on the lower spurs on either side of the Pin river, the dolomite has completely disappeared and only the lower beds of the upper and middle cambrian are found. Higher up the river also, near Baldar, the upper beds are entirely absent.

Still further to the east, in the valley of the Thanam river, near the junction of that river with the Chokdinjan Chu, the greater part of the upper and middle cambrian series has been removed. No trace is seen of the dolomite, the conglomerate being underlain by

about 150 feet of shale and slate resting upon the basal quartzites (No. 1). These in turn pass down into the red, ferruginous and carbonaceous series.

Further east, again, in the lower Thanam valley, the trilobite beds appear to be entirely absent, and on the southern side of the Hangrang Pass the silurian rocks lie upon the red and carbonaceous slates. Here, however, and indeed throughout Bashahr, the rocks are greatly disturbed, and the junctions frequently confused by faults: this is especially noticeable in the hills on the right side of the Sotlej and lower Spiti rivers, between Sungnam and Lio, where faults and granite intrusions are numerous, and the older palæozoic beds both altered and disturbed.

It has been seen, therefore, that the pre-silurian rocks of Spiti fall into three main subdivisions—
 Subdivisions of pre-silurian beds of Spiti. (c) an upper, fossiliferous series of slates, quartzites and dolomites, only the lowest beds of which have been found in the areas examined by previous observers: thickness—about 1,200 feet;

(b) a middle subdivision, consisting of bright red and black (ferruginous and carbonaceous) slates, with some quartzites; this is well developed in the Pin, Parahio and Thanam valleys, and presumably corresponds to Mr. Griesbach's upper haimantas: thickness—about 1,000 feet;

(a) a series of dark slates and quartzites, corresponding to Mr. Griesbach's middle haimantas: thickness—between 2,000 and 3,000 feet.

The age of the highest member (c) is undoubtedly upper, and possibly in part middle, cambrian, and considering the relative thickness of this and the lower subdivisions, and comparing these with the thickness of the cambrian system in other parts of the world, it would seem quite justifiable to include the whole sequence, which is a perfectly continuous one, in the cambrian system, and thus dispense in Spiti with the provisional terms "Bhabeh series," originally proposed by Stoliczka, and "Haimanta," subsequently adopted by Griesbach.

CHAPTER III.

SILURIAN SYSTEM.

Throughout Spiti the cambrian beds are overlain by a great system of shallow-water deposits, broadly consisting of conglomerates at the base, followed by grits, and passing up gradually into a thick mass of gritty quartzite, with occasional thin bands of shale.

Lower silurian conglomerate and quartzite.

The age of these rocks has hitherto been regarded as upper silurian. By Stoliczka it was included in his Muth series, of which it formed the lowest member; that series he regarded as of "upper silurian" age, but it has already been stated that he most probably included the cambrian in his silurian system, and his "upper silurian" would therefore include the whole silurian system of the present memoir.

By Mr. Griesbach the quartzite was regarded as of upper silurian age and identified by him with a similar formation found in Kumaon and Garhwál.

In Spiti, internal evidence of the age of the series is entirely wanting, for no fossils have been found in it anywhere, but it overlies—though unconformably—upper cambrian beds, and underlies a series of quartzite, shale and limestone, the lowest beds of which are almost certainly not younger than Caradoc.

The lower silurian system of Spiti has been described by Mr. Griesbach as consisting of "thin-bedded, coral limestone of dark grey colour, with occasional intercalations of siliceous and shaly beds of greenish and pink colour. Near its junction with the red quartz shales, beds of dark (fossiliferous) coral limestone alternate with the red shales, which are often replaced by greenish-grey beds of otherwise similar lithological character."¹ The thickness of this series he states to be about 300 feet.

In spite of repeated and careful search, no trace of this limestone was found below the red silurian quartzite in normal sections either by the late Dr. von Krafft or by the present writer. The section on which Mr. Griesbach's description was based is presumably that near Muth, where the beds have been somewhat disturbed, and without the assistance of the sections seen on the opposite side of the Pin river and in other parts of Spiti the true sequence might be somewhat difficult to determine.

The following may be taken as a type of the sequence of beds between the cambrian (upper) quartzites and the silurian quartzite:—

	<i>g.</i> Red, gritty quartzite, about	• • • • •	1,500 feet.
Lower Silurian.	<i>f.</i> Grit and quartzite, passing down into coarse conglomerate, which alternates with quartzite	• • • • •	100 "
	<i>e.</i> Conglomerate, composed of fragments of white quartz (often angular) in fine-grained slaty matrix	• • • • •	2 "
	<i>d.</i> Coarse, reddish and purple conglomerate	• • • • •	73 "
	<i>c.</i> Purple quartzite, with slate	• • • • •	50 "
Cambrian	<i>b.</i> Micaceous quartzite, passing down into greenish slates	• • • • •	22 "
	<i>a.</i> Purple quartzite, and slate.	• • • • •	

This section is seen near Shián, in the Pin valley, a few miles south of the village of Muth.

The slates (*c*) contain fragments of trilobites resembling those found in the lowest beds of the fossiliferous series of the Parahio valley.

The above series represents the alternating beds of "conglomerate and sandstone" described by Stoliczka as underlying the lowest subdivision ("purple rocks") of his "Muth series." Beds (*c*) and (*d*) are separated here by a fault (Pl. VIII) which continues across the Pin valley and is seen again near Muth: it does not, however, affect the section to any appreciable extent, for the sequence is almost identical with that seen in the unfaulted sections high up among the hills to the west-south-west of Muth.

On account of the unconformity which has been shown to exist between the upper cambrian beds with trilobites and the conglomerates, it has been, for reasons stated in the last chapter, considered advisable to adopt the latter as the basal bed of the silurian system. As might

be expected, the conglomerate series is itself somewhat variable, both in character and thickness. This will be seen most readily from a descrip-

Conglomerate in Pin tion of a few of the more important sections.
valley. That at Shián has already been described; but

others are seen in the high range to the south-west of Muth, near Baldar, in the upper Pin valley, in the valley of the Parahio and in the Thanam valley in Bashahr. Numerous other exposures occur, chiefly near the heads of the rivers flowing into the Spiti river from the south-west, but those enumerated above will be sufficient to indicate the salient characters of the series.

In the Parahio valley, the two sections, from which the cambrian rocks have been described, also afford typical

In Parahio valley. exposures of the lower silurian beds. In the hills on the right bank of the river, the sequence is as follows (in descending order):—

- | | |
|---|-------------------|
| 4. Pinkish-red quartzite, passing down into red-dish grit | about 1,500 feet. |
| 3. Conglomerate, composed of large pebbles of quartzite and quartz, in a fine, gritty matrix | „ 50 „ |
| 2. Hard, gritty sandstones, with pale yellowish-grey and white quartzite | „ 20 „ |
| 1. Conglomerate, composed of pebbles of quartzite, with some larger boulders of upper cambrian dolomite | „ 30 „ |

The two bands of conglomerate differ slightly from one another, for the lower bed contains, in addition to pebbles of quartzite, most of which range from three to six inches in diameter, larger pebbles of the underlying dolomite, not, however, in any great quantity; the upper bed appears to contain only quartzite and quartz, and passes through grits into the red quartzite.

In this particular section the two conglomerates are separated by a band of finer material, which is of very variable thickness, ranging from about 20 feet to a mere thread, and sometimes dying out altogether: this is the case in the section on the left bank of the Parahio (Pl. VII), where, however, the other characters are the same as those in the section just described.

Near Prádá, in the upper Pin valley, the whole of the silurian system is enclosed in a great synclinal lying on the upper cambrian slates, and cut off on either side by faults. On the opposite side of the river, behind Baldar, this synclinal caps the ridge to the north of the Bhabeh Pass and runs on to the south-east into the valley of the Tėti river in Bashahr. The conglomerate forms a very distinct and conspicuous dark band below the red quartzite.

In the valley of the Chokdinjan stream in Bashahr, at about a mile above its junction with the Thanam river, the conglomerate, which lies on the lower beds of the trilobite series, forms a single band 40 feet thick, composed of boulders of slate and quartzite in a red, gritty matrix and passes up gradually through pebble beds and grits into the overlying red quartzite.

The red quartzite calls for little notice ; except in regard to colour, its characters are constant throughout Spiti and
 Red quartzite. Bashahr. A typical section is seen at about one mile south-west of Muth, where the rock is a dark pinkish-red—at times carmine—quartzite, usually gritty and occurring in beds of about 2 feet in thickness. With it are interbedded thin layers of a lighter coloured shale. The thickness of the whole mass is about 1,500 feet. No trace of fossils was found anywhere in the quartzite or in the shales. In disturbed areas where the rocks have suffered from dynamo-metamorphism, the quartzite has undergone little alteration beyond a loss of colour. This is especially noticeable near Prádá in the Pin valley, below Pámachaung, on the path from Rupa to the Manirang Pass, at Hango, and on the south side of the Hangrang Pass; in the two last-named localities the rock is pale pink, at times almost white, and in the latter case might easily be mistaken for the "Muth quartzite," which, however, belongs to a higher horizon.

Towards the top, the quartzite becomes more thinly bedded and is gradually replaced by flaggy beds and siliceous shales, which pass up into a system of shale, marl and limestone which constitutes the middle division of Stoliczka's "Muth series" ; he describes it as a system of

"arenaceous limestone, in parts largely siliceous, with beds of purer limestone of dark colour." The fossils that he obtained from these rocks were, apparently, too fragmentary and too poorly preserved to admit of specific determination, but from their general facies he was

disposed to regard them as of silurian—probably upper silurian—age. An examination of the Silurian limestones, collections made during the last few years proves that this conclusion was correct. The age of the uppermost member of his "Muth series"—the white "Muth quartzite"—is still doubtful, but the beds between it and the red quartzite have now been found to contain fossils of both upper and lower silurian age.

Near Muth, on both sides of the Pin river, good sections of this limestone series are exposed, that on the right bank being, perhaps, the better of the two. Near Shián the red quartzite passes up through thin-bedded red and green quartzites and siliceous shales into the limestones the series falls stratigraphically, and to some extent lithologically, into the following subdivisions:—

- White "Muth" quartzite, passing gradually down into
8. Reddish-brown quartzite, underlain by grey siliceous limestone, weathering red and pink about 80 feet.
 7. Grey limestone, weathering red and brown, with red and brown marls " 70 "
 6. Grey coral limestone " 50 "
 5. Shaly limestone, with brachiopods, gastropods, and corals " 30 "
 4. Hard, grey dolomitic and siliceous limestone, with grey and green shales " 40 "
 3. Dark grey limestone, weathering brown, with *Cystidea* above and brachiopods below " 30 "
 2. Dark, foetid limestone, with shaly limestone and shale bands: brachiopods and trilobites " 200 "
 1. Shaly and flaggy sandstones and quartzite, with *Orthis* and plants, passing down through red and green thin-bedded quartzites and siliceous shales into the red quartzite " 150 "

Fossiliferous horizons.

Each of the subdivisions 1 to 8 is more or less fossiliferous.

The only fossils found in the lowest bed (No. 1) were impressions of *Orthis* sp. ind., plant remains, including *Buthotrephis* sp. cf. *gracilis*, Hall, and crinoid stems.

The overlying limestone (No. 2) contains numerous fossils, chiefly trilobites and brachiopods, the latter belonging to the genus *Strophomena*; the commonest forms are—

Cheirurus cf. *obtusatus*, Cord.

„ sp.

Illænus punctulosus, Salt.

„ sp.

Asaphus cf. *emodi*, Salt., and other species.

Calymene cf. *nivalis*, Salt.

(?) *Bronteus* sp.

Strophomena cf. *alternata*, Sow.

„ *chæmerops*, Salt.

„ *trachealis*, Salt.

„ cf. *lineatissima*, Salt.

Leptaena sericea, Sow.

Orthis, sp.

Tentaculites, sp.

Stromatopora concentrica, Goldf.

Several of the above forms are characteristically lower silurian, and the limestone is probably of Caradoc age. It will be noticed that some of the species have been identified with forms collected by Strachey in Niti¹ and described by Salter.² There is, indeed, little room for doubt that the series of limestones, shales and marls between the lower silurian red quartzite and the white (Muth) quartzite of Spiti is the western continuation of the beds from which Strachey's collections were obtained.

Above the trilobite limestone is a band of hard, grey and brown limestone (3), about 30 feet thick, which contains brachiopods in the lower layers, and *Cystidea* in the upper. The brachiopods appear to belong chiefly to *Orthis flabellulum*, Sow., with which are associated *Atrypa hemiplicata*, Hall, and corals, chiefly species of *Favosites*.

¹ Quart. Journ. Geol. Soc., vol. VII (1851), p. 303.

² Palæontology of Niti.

Near the top of the limestone is a band containing numerous *Cystidea*, chiefly *Pyrocystites pirum*, Barr., and *Craterina* sp.

This bed therefore in all probability belongs also to the lower silurian. It is overlain by about 40 feet of hard, grey limestone and greenish shale, from which no recognisable fossils have been obtained.

The next bed (5) is a shaly limestone, containing numerous badly preserved brachiopods and gastropods, with corals; most of the brachiopods are too badly preserved for identification, but include *Strophomena rhomboidalis*, Wilck., *Meristella (Atrypa) cylindrica*, Hall, *Orthis* sp.

The gastropods belong to the genus *Pleurotomaria*, and the corals to *Cyathophyllum* and *Chætetes*: *Orthoceras* sp. is also common.

This is overlain by about 50 feet of grey limestone, containing large numbers of well-preserved corals, which include—

Halysites catenulatus, Linn.

Chætetes yak, Salt.

Lyellia sp.

Favosites sp.

Cyathophyllum sp.

Syringopora sp. also occurs.

Halysites catenulatus and *Chætetes yak* are very common.

This bed appears to be Mr. Griesbach's "hard, dark, concretionary coral limestone," which he regarded as devonian.

The next bed (7) consists of shaly limestone and grey siliceous and flaggy limestone, weathering bright brownish-red.

"Red crinoid limestone."

It contains numerous fossils, mostly, however, preserved only as casts and moulds: in places the weathered surface of the rock is covered with fragments of crinoids; it therefore probably represents Mr. Griesbach's "red crinoid limestone." The shaly bands contain numerous brachiopods, of which the following are the commonest:—

Orthis thakil var. *convexa*, Salt.

" " " *sub-divisa*, Salt.

" cf. *elegantula*, Dalm.

Leptæna depressa, Dalm.

Chonetes sp.

Orthoceras sp. also occurs.

This band probably includes also Mr. Griesbach's "earthy, grey crinoid limestone."

It passes up into a series of hard, light grey, siliceous limestones, which gradually become less and less calcareous, and pass through calcareous quartzite into the reddish and brown quartzites which form the lowest beds of the "Muth quartzite."

These siliceous limestones contain a few fossils, which, owing to the hardness and homogeneity of the rock, can be seen only on the weathered surfaces; they include—

Favosites sp.

Bellerophon sp.

and badly preserved casts of cephalopods. In the Parahio valley, near Gyetzan (Gaichund), the same beds contain also numerous casts of

Pentamerus bed. (?) *Pentamerus oblongus*, Sow. The rock is unfortunately so hard that fossils cannot be extracted, and the identification of *Pentamerus oblongus* is therefore not absolutely certain, but the specimens seen on the weathered surface correspond so closely with that species that they may be referred to it with a very great degree of probability.

It is evident, therefore, that the whole series included between the Age of limestone red quartzite below and the white (Muth) quartzite above is of silurian age, and includes both upper and lower silurian beds. The lowest subdivisions (1 to 3) probably include the Caradoc and possibly lower stages, while the coral limestone may perhaps be referred to the Llandovery or Wenlock. These correlations, however, are only tentative, and until the collections have been worked out in detail, it will be impossible to recognise definite horizons with any degree of certainty; nor, indeed, has such detailed work been aimed at in the present memoir, which does not pretend to do more than give a somewhat general account of all the stratified rocks of Spiti, leaving the determination of the smaller subdivisions for future opportunities of detailed study.

The two lower subdivisions of Stoliczka's "upper silurian" or

"Muth series" have now been dealt with and their age determined with a fair degree of certainty. The uppermost Muth quartzite. member of that series is a hard, white quartzite, frequently containing brown specks of ferruginous matter. About half a mile to the west-south-west of Muth it forms a great wall of rock, nearly five hundred feet high, dipping at about 50° to the north-east. In its lower beds it is brownish and thin-bedded, and passes down very gradually into the grey, calcareous quartzites and siliceous limestones with *Pentamerus oblongus*.

No trace of fossils has been found in the quartzite, and its age can only be inferred from that of the rocks above and below it. There is little doubt that it is immediately underlain by upper silurian beds; above, it passes up gradually into a series of hard, siliceous limestones, the age of which is doubtful, but which, as will be seen in the following chapter, may belong to the devonian system. Hitherto, Stoliczka has stood alone in including the Muth quartzite in the silurian system, and it might seem undesirable, in view of the opinions expressed by subsequent observers, to adopt his classification in the present memoir, but since internal evidence of its age is entirely wanting, it has been deemed advisable to describe it with the rest of the series in which it was originally included. At present it is only possible to assert that its age is either upper silurian or devonian, and until more detailed researches shall have fixed definite horizons above or below it, the question must remain open.

In the "Manual of the Geology of India," the Muth quartzite has been included in the carboniferous system. This is mainly in consequence of the observations of Mr. Griesbach in the Kumaon and Garhwál Himálayas, and subsequently in Spiti. By Mr. Oldham, also, it was correlated with a certain white quartzite found in Kashmir among beds yielding a carboniferous fauna. This correlation was apparently based on its lithological resemblance to the Kashmir rock and also on its position at the base of Stoliczka's carboniferous "Kuling series." The only sections found along the route traversed by Mr. Oldham, *viz.*, those at Muth and Kuling, would seem to support this view, but subsequent

examination of a wider area has proved that the sequence, as seen at these two villages, is very incomplete, for in other localities the carboniferous rocks include several bands of quartzite, all exactly similar to one another and to the Muth quartzite, while one of the highest of these occurs immediately below limestones containing a rich carboniferous fauna.¹

In Kumaon and Garhwál a white quartzite has been described by Mr. Griesbach as overlying his "red crinoid limestone," and has been identified by him with the Muth quartzite,—an identification which is almost certainly correct. Since he believed the "red crinoid limestone" to be lower carboniferous, he naturally referred the white quartzite to the upper part of the same system. It has, however, now been ascertained that the Spiti representative of the "red crinoid limestone" is certainly not younger than upper silurian, and in view of the gradual passage between it and the Muth quartzite, and the complete absence of unconformity, it is safe to assert that the latter formation is not younger than devonian.

The silurian system, as described above, extends with little variation throughout the whole of Spiti. To the south-east it passes over the dividing range into the valleys of the Thanam and Tėti rivers in Bashahr (Pl. X), and can be traced along the hills on the left side of the Thanam valley to the Hangrang Pass. In this area it is of smaller extent than in Spiti, having been greatly eroded in permian times (Pl. XI); in places the whole of the Muth quartzite and silurian limestone have been removed and the permian beds are found resting on the red, lower silurian quartzite. Similar erosion of the Muth quartzite was noticed by Mr. Griesbach in Niti.²

To the north-west the silurian beds are found at Trákse, near Losar in upper Spiti, on the road to the Kunzam Lá, where they are

¹ It is not, however, intended to imply that this quartzite is necessarily the equivalent of the Kashmir band.

² Memoirs, G. S. I., vol. XXIII, p. 62.

considerably crushed and faulted, but in other respects similar to the type series at Muth. From the summit of the Kunzam Pass they can be seen running northwards along the left side of the Chandra valley, and, further on, their presence has been recorded by Stoliczka in North Lahaul.¹ Here he found traces of *Orthis* and trilobites in a light-coloured limestone, which, however, he referred to his Bhabeh series (Cambrian of this memoir). It is possible that the limestone may represent the Cambrian dolomite of the Parahio, but there is no trace of this rock in the intervening area, *i.e.*, in upper Spiti and on the Kunzam Lá, where the lower Silurian conglomerate rests on the lower beds of the upper Cambrian, and it is probable that the Lahaul rock is really Silurian. This, unfortunately, cannot be ascertained by reference to Stoliczka's collections, which, with the rest of his and Mr. Griesbach's Palæozoic fossils, have been for many years in England awaiting description.

How far this system may be represented in Kashmir it is at present impossible to say. The lower conglomerates and quartzite may possibly find their equivalents in Lydekker's Panjál system, to which they appear to have some lithological resemblance, but, as will be seen below (p. 57), certain beds, which occur at a very much higher horizon, have also lithological characters very similar to those of the Panjál rocks, and it is therefore unsafe to attempt any correlation on this basis. Nor do the stratigraphical features of the Panjál rocks offer any assistance, for they do not appear to include any fossiliferous beds similar to either the Cambrian or the Silurian of Spiti, while their structural conditions are so highly complicated by supposed inversions of the strata, that in many cases their true relations to the now under- and over-lying beds may be the reverse of what they appear, and until fossils have been found in the older Palæozoic rocks of Kashmir, the only hope of correlating them with those of Spiti will lie in tracing the series of known age continuously from one area into the other.

¹ Memoirs, G. S. I., vol. V, p. 341.

In the face of such difficulties in the immediate neighbourhood of Spiti, it might seem futile to go still further afield, and beyond Kashmir, in search of an equivalent of the silurian system of Muth, but it is necessary to refer to an interesting paper recently published by General McMahon and Mr. Hudleston,¹ dealing with a series of fossils collected by Captain Gurdon on the bank of the Chitral river,

Red sandstone, conglomerate and devonian limestone of Chitral.

between Chitral and Mastuj. An account of the rocks of the locality was contributed by Major McMahon, who mentions three distinctive horizons, *viz.*, a conglomerate, a red sandstone, and a limestone. The conglomerate is the lowest, and is overlain by the red sandstone. The limestone, which is the uppermost member of the series, yielded the fossils which have been described by Mr. Hudleston, who considers that they are undoubtedly devonian. Major McMahon does not say whether the limestone *immediately* overlies the red sandstone or is separated from it by other beds, but his diagrammatic sketch² does not preclude the latter possibility. Should the conglomerate and sandstone correspond to the conglomerate and red quartzite of Spiti, the devonian limestone might be the equivalent of the limestones which immediately overlie the Muth quartzite, and which may very possibly be of devonian age.³

[In this connection it is interesting to note that a few years ago a small collection of fossils was sent to the Geological Survey of India by Lieutenant Grant from the Baroghil Pass in Chitral. They consist of fragments of a trilobite (*Phacops* sp.), a *Spirifer*, *Orthis*, and some *Bryozoa* in a compact, grey limestone. The materials are not sufficiently good to admit of specific determination, but they resemble devonian species.]

In the annexed table will be found the correlation and subdivisions of the lower palæozoic beds of Spiti adopted respectively by Stoliczka, Griesbach and the present writer.

Subdivision and correlation of lower palæozoic beds.

¹ Geol. Magazine, January and February 1902.

² Geol. Magazine, January 1902, p. 5, fig 2.

³ *Infra*, p. 34.

STOLICZKA. (Memoirs, G. S. I., vol. V.)	GRIESBACH. (Memoirs, G. S. I., vol. XXIII.)	PRESENT MEMOIR.	
(?) UPPER SILURIAN. Muth quartzite. Arenaceous and siliceous limestone. Purple quartzite, with conglomerate at base.	(?) UPPER SILURIAN. White (Muth) quartzite. Red crinoid limestone. Earthy, dark grey limestone.	CARBONIFEROUS. Muth quartzite. Grey siliceous limestone, weathering red. Grey limestone, weathering reddish brown, with brown and red marls. Grey coral limestone. Shaly limestone, with <i>brachiopods</i> , <i>gastropods</i> and <i>corals</i> . Hard, grey dolomitic limestone. Dark grey limestone, with <i>Cystidea</i> . Dark, fossiliferous limestone, with <i>trilobites</i> and <i>brachiopods</i> . Shaly and flaggy sandstone, with <i>plants</i> .	(?) UPPER SILURIAN. (?) UPPER (Boundary doubtful.)
		DEVONIAN. Dirty, flesh-coloured quartzite.	LOWER Flaggy quartzite and siliceous shale passing down into great mass of red quartzite, underlain by conglomerate.
LOWER SILURIAN. Green and bluish micaceous and laminated sandstone, with Grey siliceous sandstone, with occasional calcareous beds (dolomitic), with blue and red shales. Bluish grey slates and sandstones.	HAIMANTA. Red quartz shales. Slates, quartzites and conglomerates, merates,	SILURIAN. LOWER UPPER	CAMBRIAN. UPPER (AND (?) PARTLY MIDDLE)

CHAPTER IV.

DEVONIAN (?), CARBONIFEROUS AND PERMIAN.

It is a curious fact that although rocks of devonian age had long been known to occur on either side of the Indian Empire, yet, until quite recently, none had been found in the intervening area. During the field season of 1899-1900, Mr. T. D. La Touche, assisted by Mr. P. N. Datta, made the first discovery of devonian fossils, in the Northern Shan States, and during the subsequent season, Mr. La Touche succeeded in obtaining a large collection of well-preserved and thoroughly characteristic species. Almost simultaneously with Mr. La Touche's discoveries in the most easterly part of the Empire, the collection of devonian fossils mentioned in the last chapter was made by Captain Gurdon, in the Hindu Kush, thus bringing the devonian beds almost to the confines of the Himálayas, but as yet no fossils which could be unequivocally referred to that system have been discovered in this great mountain range.

In the Niti area and in Spiti, Mr. Griesbach has described a "hard, dark, concretionary coral limestone," varying in thickness from 650 to nearly 1,000 feet, which he believed to be of devonian age. This correlation, however, is not based on the evidence of fossils, but depends on the fact that the limestone overlies the red quartzite, regarded by him as of upper silurian age, and underlies the "red crinoid limestone" which he ascribed to the carboniferous system. From the section south of Muth, in Spiti, he describes his devonian system as "a thickness of from 700 to 800 feet of a very dark, hard limestone, concretionary in parts, alternating with dark, splintery shales."¹ This can only represent the limestone series, described in the last chapter, which overlies the red silurian quartzite and has now been found to

¹ Memoirs, G. S. I., vol. XXIII, p. 214.

contain lower, and probably also upper, silurian fossils. It is evident, therefore, that the Himálayan equivalent of the devonian system must be sought for at a higher horizon, which, as already shown, must be situated at least above the base of the Muth quartzite.

In the valleys of the Lipak and Yulang rivers in Kanaur, this Devonian in Bashahr. quartzite passes up, through shaly beds and narrow bands of quartzite, into a series of siliceous and shaly limestone, with hard, nodular, coral-bearing bands. At about 80 feet above the Muth quartzite is a bed of grey limestone containing corals, crinoids and brachiopods. The matrix is very hard and siliceous, and the fossils are most clearly seen on the reddish-brown weathered surface of the rock. They are unfortunately all badly crushed and cannot be determined with any degree of certainty, but the brachiopods include large numbers of a form very closely resembling *Streptorhynchus umbraculum*, Schloth., with species of *Orthis*, *Atrypa aspera*, Schloth., and *Cyathophyllum* sp. These beds form the base of a series of dark, splintery limestones, about 300 feet thick, in which, with the exception of four bands of coral limestone, no other fossiliferous horizons have been found.

The coral bands occur at intervals through the limestone, and vary in thickness from 1 to 3 feet. They appear to be composed entirely of a species of *Cyathophyllum*, but the original fossils have been almost entirely replaced by crystalline calcite and silica, and their internal structure to a great extent obliterated. It is possible that this series may represent the whole or a part of the devonian system, but in all the localities visited, the fossils are too badly preserved for reliable determinations.

It has already been stated that the palæozoic beds have undergone erosion, which took place between carboniferous and permian times; owing to this, the limestone just described is frequently wanting in the palæozoic sections. In Spiti, however, it is found at Trákse, near Losar, where it is greatly crushed, but contains brachiopods similar to those found in the Yulang valley. The same beds probably occur at Muth also, but no determinable fossils have been found.

It was believed by Stoliczka that the palæozoic systems of Spiti comprised two distinct facies, termed by him the Stoliczka's "southern and eastern facies." *southern* and the *eastern* respectively. The *southern* facies was that exposed in the Pin valley, where the section includes the older palæozoics described in the last two chapters, and regarded by Stoliczka as silurian. In the *eastern* facies he included a great series of shale and quartzite found in the lower Spiti valley, at and beyond the village of Po; this he identified with his Bhabeh and Muth series, considering it probable that the relationship of the two facies to one another would be ascertained by an examination of that part of Kanaur lying immediately to the south-east of Spiti. This area was examined for the first time in any detail by the present writer in 1899, and it was definitely ascertained that the eastern was not the equivalent of the southern series, but was very much younger.

At Muth the white (Muth) quartzite passes up through arenaceous Carboniferous beds and shaly beds into a mass of dark limestone, at Muth. which has a thickness of between 300 and 400 feet, and has yielded a considerable number of fossils, mostly, however, rather badly preserved. Further down the Pin valley, at Kuling, the same limestone is again seen; it is perhaps a little thicker here, but is in other respects similar to that seen at Muth. At each of these localities the limestone is overlain unconformably by a conglomerate followed by a bed of calcareous sandstone and black shales (the "Productus shales"). It will subsequently be seen that these upper beds are of permian age.

The unconformity between the permian beds and the underlying Carboniferous-permian limestone was first noticed by Stoliczka and subsequently confirmed by Griesbach, who had also observed a similar break at the base of the permian beds in the more easterly parts of the Central Himálayas.¹ As the horizon of the white quartzite is followed from Muth towards the south-east, the permian beds are found to rest on lower and lower horizons of the underlying

¹ Memoirs, G. S. I., vol. XXIII, p. 63.

systems, till in the Thanam valley they lie on the red, lower silurian quartzite; as they are traced further eastwards, the upper beds of the silurian re-appear, till at length, near Hango in Kanaur, a few patches of the Muth quartzite are found; these gradually pass into the full thickness of that formation, and in the valley of the Lipak river, the upper palæozoic systems occur in the fullest development to which they have hitherto been known to attain in the Himálayas.

Here the Muth quartzite is overlain by a series of limestone and quartzite over 2,000 feet thick, which is in turn succeeded by an even greater thickness of dark shale and quartzite, passing up near Po, in the Spiti valley, into conglomerate and calcareous sandstone, which immediately underlie the permian "Productus shales." This great series, the total thickness of which, including the "Productus shales," cannot be less than 5,000 feet, represents the carboniferous and permian—and probably also devonian—systems of the Himálayas.

Lithologically, the series falls into two subdivisions, a lower consisting of quartzite and limestone, and a higher composed of quartzite and shale.

The lower subdivision is found in its fullest development in the hills above Lio in Kanaur, where it forms the ridge separating the Lipak and Yulang rivers. At the opposite end of Spiti, at the head of the Spiti river, it is also largely developed, but the total thickness is probably less than in Kanaur; the beds, however, are crushed and faulted, and only a few of the Lipak horizons can be recognised.

At the point where the upper mountain track to Hango leaves the Lipak river, the hills on either side of the stream rise sharply up in steep precipices to a height of some 4,000 feet above the river; those on the left bank form one side of the ridge which separates the Lipak and Yulang rivers. Near the summit of the ridge is the camping-ground of Tangá, between which and the river below the rocks afford a section of almost the whole of the silurian system, with the Muth quartzite and the overlying limestone and quartzite series. Near the middle of the section a bright, reddish-

brown band represents the weathered silurian limestone, above which the white Muth quartzite forms an equally striking horizon.

The total thickness of the succeeding limestone and quartzite series is probably almost 2,000 feet; the section was measured from the top of the Muth quartzite up to the camping-ground of Ták-rá-chen, which is a little below Tangá, but owing to the physical difficulties involved, the following measurements are only approximate:—

“Po series” of shale and quartzite.

7. Yellow and buff limestone. Dark, flaggy limestone, hard and splintery	} 500 feet.
6. Limestones, with thin bands of soft shale; fossiliferous horizons occur at the following heights above the white quartzite No. 5:—	
Grey shale (horizon <i>g</i>), 372 feet above No. 5	
Limestone (<i>f</i>), 303 ” ” ” ”	
Shale (<i>e</i>), 263 ” ” ” ”	372 ”
Limestone (<i>d</i>), 188 ” ” ” ”	
Shale (<i>c</i>), 123 ” ” ” ”	
Shale (<i>b</i>), 117 ” ” ” ”	
Flaggy limestone. } (<i>a</i>), extending from 12 feet to 37 feet above No. 5	
5. White quartzite	25 ”
4. Hard, dark limestone, containing apparently only crinoids	185 ”
3. White and grey quartzite, with purple slates and subordinate bands of flaggy limestone	224 ”
2. Limestone, weathering yellow and reddish-brown	131 ”
1. Hard, dark grey and black splintery limestone in beds of from 2 feet to 4 feet thick, with coral bands at 283'-4', 262'-5', 152'-5', 95'-97'	360 ”

Total thickness 1,797 feet.

Muth quartzite.

The lowest subdivision (No. 1) of the above series has already been described. With the exception of the bands of corals, no fossils were found in it between the Lipak river and Ták-rá-chen: sections of brachiopods were seen in the rock, but nothing could be extracted. On the opposite side of the ridge at about 1,000 feet above the Yulang river, the fossils

already mentioned (*supra*, p. 34) were found; as stated above, they are too badly preserved to afford definite proof of the age of the limestone, but it may perhaps represent part, at least, of the devonian system.

With the exception of crinoid remains in No. 4, the overlying beds (2 to 5) have yielded no fossils, and their age is therefore uncertain. The two quartzites, Nos. 3 and 5, closely resemble the Muth quartzite, for which they might very easily be mistaken. They are seen in the Yulang river and again at Gyumdo E. G. on the left bank of the Spiti river, in the Tibetan province of To-tzo (or Tso-tso), where they and the accompanying limestones have been greatly altered by contact-metamorphism. Here they were supposed to represent the Muth quartzite, but the subsequent discovery of the series in the Lipak river proved that this correlation was erroneous.

The third quartzite (No. 5) passes up into a series of limestones (6) with thin partings of shale. This subdivision is more or less fossiliferous throughout its whole extent, but the beds have been often much crushed and folded, and the fossils are in many cases too badly preserved for identification. Certain horizons, however (*a* to *g*, Pl. II), were found, in which the fossils were in a very fair state of preservation, and from these a large collection was obtained.

Horizon (a).—The lowest horizon (*a*) occurs about 12 feet above the uppermost white quartzite (No. 5), and consists of a highly fossiliferous band of rock of about 25 feet in thickness. The specimens obtained from this bed include the following forms:—

- Productus cora*, d'Orb.
- „ *semireticulatus*, Mart.
- „ sp.
- Chonetes hardrensis* var. *tibetensis*, Dav.
- Syringothyris cuspidata*, Mart.
- Spirifer* cf. *kashmiriensis*, Dav.
- „ sp.
- Strophomena analoga*, Phill.
- Reticularia lineata*, Mart.
- Athyris royssii*, Lév.
- „ *subtilita*, Hall.
- (?) *Retzia* sp.

Discina sp.
Conocardium sp.
Aviculopecten sp.
Platyceras sp.
Pleurotomaria sp.
Phillipsia cf. *cliffordi*, Woodw.
Helodus crenulatus, Newberry and Worthen.
Polypora sp. and numerous crinoids.

With these occur numerous specimens of *Orthotetes* sp. or *Derbyia* sp., resembling *D. senilis*, Phill., but the internal characters cannot be distinguished, and it is consequently impossible to refer them definitely to either genus.

There can be no doubt that the age of the beds in which the above fossils occur is carboniferous, and though some of the forms are common to the whole of that system, yet, from the presence of *Syringothyris cuspidata*, *Phillipsia* cf. *cliffordi* and *Helodus crenulatus*, it seems probable that the limestone is of lower carboniferous age. The same horizon has been recognised at Muth and Kuling in the Pin valley and Trákse, near the head of the Spiti river.

Horizon (b).—This is a band of shale, $3\frac{1}{2}$ feet in thickness, which occurs at about 117 feet above the top of the white quartzite (No. 5).

The fossils, though numerous, are much crushed and are often merely casts or impressions; they consist chiefly of large numbers of—

Spirifer sp.
Discina nitida, Phill.
 „ cf. *newberryi*, Hall.
Lingula cf. *mytiloides*, Sow.
Pleurotomaria sp.
Retzia sp.

Horizon (c).—About six feet higher up another band of shale contains impressions of—

Spirifer sp.
Rhynchonella pleurodon, Phill.
Aviculopecten sp.
Orthoceras sp.

The *Spirifer* and *Rhynchonella* are very common.

Horizon (d).—This horizon consists of a highly fossiliferous band

of limestone, occurring at about 188 feet above the quartzite (No. 5); it has yielded the following forms:—

Productus cora, d'Orb.
 „ *semireticulatus*, Mart.
Syringothyris cuspidata, Mart.
Spirifer, sp.
Rhynchonella pleurodon, Phill.
 „ „ var. *davreuxiana*, de Kon.
Athyris royssii, Lév.
 „ *subtilita*, Hall.
Chonetes hardrensis, Phill.
Strophomena analoga, Phill.
Aviculopecten sp.
Euphemus urii, Fleming.
Pleurotomaria sp.
Platyceras sp.
Conularia cf. *quadrisulcata*, Miller.
Chætetes radians, Fisch.

It will be seen that the forms found at this horizon are to a great extent the same as those obtained from the lowest band (a), and it is therefore probable that the whole series from the top of the white quartzite (No. 5) to this horizon is of lower carboniferous age.

Horizon (e).—At about 75 feet above the last horizon, a band of shale, 1 inch in thickness, has yielded the following forms:—

Rhynchonella pleurodon, Phill.
Chonetes hardrensis, Phill.
Spirifer sp.
Discina cf. *newberryi*, Hall.
Orthoceras sp.
Psammodus sp.

and numerous casts of a bivalve. Immediately above this is a band of limestone with—

Productus cora, d'Orb.
Rhynchonella pleurodon, Phill.
Orthotetes (?) sp.
Aviculopecten sp.
Euomphalus sp.¹

¹This is a small specimen closely resembling *E. hecale*, Hall, from the devonian of New York.

Horizon (f).—Forty feet higher up another band of limestone contains numerous fossils including—

Productus cora, d'Orb.

Productus semireticulatus, Mart.

Spirifer sp.

Athyris royssi, Lév.

Rhynchonella pleurodon, Phill.

Orthotetes (?) sp. (or *Derbyia* sp., resembling *Derbyia regularis*,
Waagen).

Terebratula sp.

Fish teeth.

Horizon (g).—The highest horizon in this series at which fossils were found is a band of light grey, micaceous shale, 372 feet above the white quartzite (No. 5). This bed contains immense numbers of *Estheria* sp.; they all appear to belong to the same species, which is probably new and does not therefore throw any further light on the age of the shale.

It will be seen from the above lists of fossils, imperfect though they are, that most of the forms found in the lowest horizon (*a*) occur also at higher horizons, and it is therefore probable that the whole series from the top of the white quartzite (No. 5) to the *Estheria* bed, belongs to one and the same subdivision of the carboniferous system, while the presence of *Syringothyris cuspidata* renders it probable that that subdivision is the lower.

The fossiliferous beds pass up into a mass of limestone about 500 feet thick, of which the lower beds are hard, dark and flaggy while the upper consist of yellow and buff crystalline limestone. In the Lipak and Yulang valleys the uppermost beds have been in many places converted into a very pure, white gypsum. Similar alteration of the carboniferous limestone has taken place at several other localities, including Gyumdo E. G. in To-Tzo, Huling in lower Spiti, the Sumra Lá (between Sumra and Shálkar), Tangá Chenmo in the Gyundi valley in upper Spiti, and above Trákse E. G. near the head of the Spiti river. This alteration is not confined to the upper beds, but occurs at various horizons in the carboniferous limestones.¹

¹ For a fuller description of the gypsum, see below, p. 101.

The thickness and extent of these beds overlying the Muth quartzite is very variable. They occur in their fullest development in the section just described. In the Thanam valley they have been completely removed by permian or pre-permian denudation, but re-appear to some extent in Spiti, and at Muth in the Pin valley are represented by about 450 feet of siliceous limestone, calcareous sandstone and dark, fossiliferous limestone. At about the middle of the series the limestone contains large numbers of *Syringothyris cuspidata*, Mart., *Spirifer* sp., *Dielasma* sp. and *Rhynchonella pleurodon*, Phill., and 50 feet lower down a band was found almost entirely composed of *Rhynchonella pleurodon*. These beds almost certainly represent the fossiliferous limestones (No. 6) of the Lipak river, but the underlying beds which, in the latter locality, are about 1,000 feet thick must be represented at Muth by less than 100 feet of limestone, calcareous sandstone and quartzite, and since the horizontal distance between Lio and Muth is only between 30 and 40 miles, this must involve a remarkably rapid thinning out of the lower beds from east to west.

To the north of Muth, at Kuling on the Pin river, the beds immediately below the permian unconformity are dark, flaggy limestones, apparently unfossiliferous, but underlain by a limestone very similar to horizon (a) of the Lipak section. The commonest fossils are—

Productus cora, d'Orb.
 „ *semireticulatus*, Mart.
Rhynchonella pleurodon, Phill.
Syringothyris cuspidata, Mart.

With these occur also—

Reticularia lineata, Mart., and *Orthotetes* (or *Derbyia*) sp.

This band, which is seen just below the path from Kuling to Kungri, and again on the road from Kungri to Mikkim, is underlain by a thin bed of quartzite which passes down into hard limestones and quartzites overlying the Muth quartzite. The beds below the fossiliferous lime-

stone appear to be thinner than in the Lipak section but thicker than at Muth.

Among the Kashmir and Spiti fossils described a few years ago by Professor Diener are two badly preserved specimens of a form identified by him with *Syringothyris cuspidata*, Mart.¹ They are said to have been "obtained near Kuling in Spiti, by Dr. Stoliczka, from a black crinoidal limestone." Professor Diener continues as follows: "There is some probability of this rock specimen having been derived from the crinoid limestone horizon which Griesbach has demonstrated to underlie the white quartzite of Spiti, and which he correlates with the mountain limestone of Europe. If this probability could be proved, the presence of *Syringothyris cuspidata* would be strongly in favour of Griesbach's correlation."² The limestone referred to is Griesbach's "earthy, grey crinoid limestone" which constitutes bed No. 7 of his sequence (Memoirs, G. S. I., vol. XXIII), and which underlies the "red crinoid limestone." At Muth, however, the grey limestone in question has already been shown to be certainly not younger than upper silurian, nor does it in any respect resemble the black oölitic and crinoidal limestone in which *Syringothyris cuspidata* occurs both at Muth and at Kuling: the latter limestone is, in fact, Griesbach's "upper carboniferous (8a)," and the presence in it of *Syringothyris cuspidata*³ is, as Dr. Diener remarks, strongly in favour of its being of lower carboniferous age. It may be added that Griesbach's "earthy, grey crinoid limestone," is not seen at Kuling, nor, indeed, within many miles of that village, the lowest bed exposed being the Muth quartzite, which forms the core of an anticline between the villages of Khár, on the right bank of the Pin river, and Kungri, on the left; only the uppermost part of the quartzite is seen at the river-side below

¹ Since the above was written, Professor Diener's descriptions of the Spiti fossils, collected by Dr. von Krafft and the present writer in 1899, have reached India and are being published in Pal. Indica, Himalayan Fossils, vol. I, pt. 5. With regard to the identification of the Spiti fossil with *Syringothyris cuspidata*, Mart., see pp. 147-150 and Appendix to that memoir.

² "Anthracolithic fossils of Kashmir and Spiti," Pal. Indica, ser. XV, vol. I, pt. 2, p. 76, and pl. IV, figs. 9, 10.

³ *Ibid.*, p. 95.

Kungri, while the limestone with *Syringothyris* is well exposed near the village, although that fossil is not perhaps so common as either at Muth or in the Lipak section.

To the north-west of Muth, in the valley of the Parahio, near the village of Gyetzan (Gaichund), the carboniferous beds and the greater part of the Muth quartzite have been cut out by a fault, but re-appear in the upper reaches of the Rátang (Pl. I, fig. 1) and Gyundi rivers (Pl. III, fig. 1), where their thickness is little, if at all, greater than at Muth. In the high ranges, however, between the Gyundi river and the village of Losar, the beds rapidly thicken, and near Trákse, at the head of the Spiti river, the series is thicker than in any other part of Spiti, though apparently not so thick as in the Lipak valley in Kanaur. At Trákse the beds have been greatly disturbed and crushed,

Carboniferous of upper Spiti. but still contain numerous fossils, which are, however, badly distorted. The lowest horizon recognised is that containing (?) *Streptorhynchus umbraculum*, Schloth., and other brachiopods, already described from the Yulang valley as of possibly devonian age (*supra*, p. 34). This is overlain by limestone and quartzites, above which are flaggy limestones, representing horizon (a) and containing large numbers of distorted specimens of *Productus*, *Chonetes* and *Rhynchonella*: the beds between these two fossiliferous horizons are about 500 feet thick. The upper horizon is overlain by a series of flaggy limestones, which represent the uppermost subdivisions (Nos. 6 and 7) of the Lipak series.

Before attempting to correlate these beds with supposed carboniferous rocks of other areas, it will be advisable to describe the overlying shales and quartzites, which are found in upper and lower Spiti and Kanaur, and which constitute Stoliczka's "eastern facies." Owing to their remarkable development in the neighbourhood of Po, they may be conveniently termed the "Po series,"¹

¹ In spite of the desirability of eliminating local names, this is not possible in the present instance, for the age of these beds is still uncertain and they cannot be definitely referred to either of the upper palæozoic systems.

At the head of the Lipak river, the uppermost carboniferous limestones are overlain by alternating beds of shale and quartzite. The thickness of the series is variable: it appears first on the right side of the Lipak river, where the total thickness of the shale and quartzite is small, but to the north, towards Spiti it increases, and in the ranges on either side of the Spiti river below Po it is not less than 2,000 feet. Near Sumra and Lari the lower beds of the series consist of shale and quartzite, the former predominating. The quartzites are yellowish, brownish or white, and often resemble the Muth quartzite. The shales are usually black, but near Sumra are reddish-brown and schistose; this is due to contact-metamorphism, numerous dykes and sheets of basic igneous rock (amphibolite and altered dolerite) occurring among the sedimentary beds. In the neighbourhood of the intrusions, the shales have been converted into hard slates and pyritous and garnetiferous mica schists. One of these dykes runs for several miles along the hillside between Sumra and the pass (Sumra Lá or Shálkar Lá) leading into Kanaur, and is seen again in the hills on the left side of the Spiti river, opposite Sumra; it is of very uniform thickness and is inclined at a low angle to the bedding-planes of the shale and quartzite: it thus frequently resembles, and is at times, a sheet, and it is probable that it was mistaken by Stoliczka for a contemporaneous trap flow, for he states that "between

Supposed contemporaneous trap.	Changrizang and Po. beds of greenstone [occur] all through the series not in veins, but in regular beds between the other
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rocks." A careful examination was made by the present writer of all the igneous rocks seen between Po and Changrizang, and in every case they have been found to be intrusive, and although, at times, they take the form of sheets, yet if followed for any distance, they invariably cut across the bedding-planes of the sedimentary beds. These apparent sheets can be seen in the neighbourhoods of Sumra and Lari, while near Po—about $\frac{3}{4}$ mile north-east of the village—the path

¹ Memoirs, G. S. I., vol. V, p. 20.

passes over a mass of dolerite which has been intruded along a fault running at right angles to the strike of the shales and quartzites. This point is one of considerable importance, for the supposed existence of contemporaneous trap-flows in these beds in Spiti has been used as an argument in favour of their correlation with Lydekker's "Panjál, system" of Kashmir.

Normally, then, the series overlying the carboniferous limestones consists of dark shales and quartzites: in the lower part of the series shales predominate, but towards the top the two rocks alternate rapidly and the quartzite bands increase in thickness, till the series becomes one of quartzite and grit—often calcareous—with thick beds of coarse conglomerate; these pass up into a gritty, calcareous sandstone, from 40 to 150 feet thick, overlain by a bed of black and dark brown shale (the "Productus shales"). The two last-named beds—calcareous sandstone and Productus shales—are invariably present throughout Spiti and Bashahr, and constitute the uppermost members of the palæozoic group. As already stated, they are in most sections unconformable to the beds on which they rest, but in the northern parts of Kanaur, and in upper and lower Spiti, the underlying beds occur in their fullest development, and there is no evidence of unconformity, for the conglomerates pass up gradually, through calcareous grits, into the calcareous sandstone.

The complete sequence of the upper palæozoic systems is therefore as follows:—

- | | | |
|--|---|--------------------------------------|
| 5. Productus shales : | } | Permian. |
| 4. Calcareous sandstone : | | |
| 3. Conglomerate, grit and quartzite : passing down
into | | |
| 2. An alternating series of shale and quartzite : | } | Upper carboniferous
and Culm. |
| 1. Limestones and quartzites of the Lipak river. | | |
| | } | Lower carboniferous
and devonian. |
| | | |

The lowest group (No. 1) has already been described.

In the next group fossils are very rare, and have been found only at three horizons between Po and Thábo. The lowest horizon is a band of green and greyish-green shales, which is exposed on the left bank of the Spiti river, about $1\frac{1}{4}$ mile above Thábo. The only outcrop hitherto observed occurs under a band of quartzite at the water's edge, and during the summer floods is frequently inaccessible. It has yielded only poorly preserved plants; these, however, have been examined by Professor R. Zeiller, to whom the writer is greatly indebted for the following note sent through Mr. R. D. Oldham:—

"The specimens collected in Spiti by Mr. Hayden comprise a fragment of a simply pinnate frond and numerous pinnulæ of a fern with cyclopterid venation, which does not appear to differ appreciably from *Rhacopteris inæquilatera*, O. Feistmantel (*non* Goeppert sp.) from the Culm of Smith's Creek, Port Stephens, and Arowa, New South Wales. I have noticed also a very small fragment of a pinna of another fern very similar to *Sphenopteridium furcillatum*, Ludwig (sp.), from the Culm or devonian of Hesse-Nassau, but the specimen is too fragmentary for specific determination. There are also small fragments of a fern recalling *Sphenopteris rigida*, Ludwig, from the same formation, but which are still less fit for definite identification. It is difficult to draw any certain conclusion from these materials as to the age of the beds in which they occur, yet the identity of the fern most largely represented with *Rhacopteris inæquilatera* from the Culm of New South Wales seems to me sufficiently probable to warrant the inference that the beds belong to the same horizon as those of Arowa and Port Stephens."¹

¹ "Les échantillons recueillis à Spiti par M. Hayden comprennent un fragment de fronde simplement pinnée et de nombreuses pinnules d'une Fougère à nervation cycloptéroïde, qui me paraît ne différer par aucun caractère appréciable du *Rhacopteris inæquilatera*, O. Feistmantel (*non* Goeppert sp.), du Culm de Smith's Creek, Port Stephens et Arowa dans la Nouvelle-Galles du Sud. J'y ai remarqué en outre un très petit fragment de penne d'une autre Fougère très analogue au *Sphenopteridium furcillatum*, Ludwig (sp.), du Culm ou Devonien de la Hesse-Nassau mais l'échantillon est trop fragmentaire pour être déterminé spécifiquement. Il en est de même de petits lambeaux de Fougère qui rappellent le *Sphenopteris*.

It is highly probable, therefore, that the lower part of the shale and quartzite series is homotaxial with the Culm, while it is particularly interesting to note that the only form which has been identified with any certainty belongs to an Australian species. The presence of Culm beds overlying the limestones of the Lipak river is a further proof, if such were needed, that the latter should be referred to the lower, and not to the upper, carboniferous.

Two other horizons are seen in the ridge north-east of Po, a few hundred feet above the path to Thábo. The lower horizon is a black shale with concretions, which frequently contain well-preserved fossils, chiefly *Brachiopoda*. The shales in this locality are everywhere full of concretions, but although many hundreds of these have been broken open, they have been found to contain fossils at only this one horizon, which consists of two rows of concretions separated from one another by about two feet of shale; in the lower row, fossils are rare and consist chiefly of species of *Nautilus*, while the upper band contains *Brachiopoda* and *Bryozoa*.

The small collection of fossils obtained from this horizon comprises the following forms:—

- Productus scabriculus*, Martin.
- „ *lineatus*, Waagen.
- Dielasma*, sp.
- Spirigera* sp. cf. *gerardi*, Diener.
- Reticularia lineata*, Mart.
- Spirifer* cf. *triangularis*, Mart.
- Nautilus* sp.
- Orthoceras* sp.
- Pleurotomaria* sp.
- Fenestella* sp.

rigida Ludwig de la même formation, mais qui sont encore moins susceptibles d'une détermination certaine.

En résumé, il est difficile de tirer de ces matériaux une conclusion tout à fait sûre en ce qui concerne l'âge des couches dont ils proviennent; cependant l'identité de la *Fougère* la plus abondamment représentée avec le *Rhacopteris inæquilatera* du Culm de la Nouvelle-Galles du Sud me paraît assez probable pour me donner lieu de penser que ces couches doivent appartenir à peu près au même niveau que celles d'Arowa et Port Stephens."

Higher up on the same ridge another bed of shale contains immense numbers of *Bryozoa*, with a few badly preserved brachiopods; the collections made from this horizon were sent to Europe for description, and are not therefore available for examination, but the present writer is greatly indebted to Professor Diener, to whom the specimens were sent, for the information that "the *Bryozoa* appear to be identical with the leading species from the Zewán beds of Kashmir." Dr. Diener also adds that "among the *Brachiopoda* there is a species of *Productus* which is either identical with, or very nearly allied to, *P. scabriculus*, Mart."¹

Owing to the innumerable alternations of exactly similar beds of shale and quartzite, it has been found advisable to take advantage of any peculiarities in order to distinguish the various beds, and in consequence of the large numbers of *Bryozoa*—chiefly belonging to the genus *Fenestella*—found in this band, it has been named the "Fenestella shales."

The same bed crops out again about half way between Po and Thábo (Pl. XII), at Lanjarje E. G., on the left bank of the Spiti river, where the path leaves the level of the stream and turns suddenly up a steep ascent of shale: at the top of the slope the path passes over the same black shales full of impressions of *Bryozoa*, and there is little doubt that the horizon is the same as that seen above Po where, however, the beds have been greatly disturbed by faults and the relative positions of the two fossiliferous horizons there exposed are somewhat doubtful, it being uncertain whether the shale with concretions is in reality older than the Fenestella shales, although the latter appear to occupy a considerably higher horizon.

¹ Since writing the above, the author has had access to Professor Diener's description of the fossils from this horizon; they include—

Productus undatus, Deffr.

„ *scabriculus*, Mart.

„ *nystianus* var. *lopingensis*, Keyser.

Fenestella sp. ind. aff. *F. plebeia*, M'Coy.

Protoretetpora ampla, Lnsd.

Above Lanjarse there is a fairly complete section of the beds overlying the *Fenestella* shales, but no trace of the band of fossiliferous concretions was found, and it is therefore probable that at Po these two horizons are in their true positions relatively to one another. This could not be ascertained definitely at Lanjarse, for the *Fenestella* shales, underlain by a bed of quartzite, form the base of the section. It is probable, however, that the two horizons are not separated from one another by more than a small thickness of rock, for the same species of *Bryozoa* are numerous in both, and they should perhaps be grouped together as one horizon; this can only be determined by a more detailed examination of the sections between Po and Thábo, and opposite Thábo, on the right side of the Spiti river; the latter locality, though difficult of access, appears to offer a more continuous section and one well adapted to detailed study.

At Losar, however, near the head of the Spiti river, the *Fenestella* shales, which are found in the high hills behind the village, contain brachiopods (including *Productus scabriculus*, Mart.) exactly resembling those found in the concretionary band near Po. This constitutes a further argument in favour of including the latter band with the *Fenestella* shales.

With regard to the age of these beds the collections obtained are, it is feared, too small to offer conclusive evidence, but owing to the presence of such large numbers of *Bryozoa*, it was originally suggested by the present writer¹ that they might correspond to the Zewán beds² of Kashmir. This question cannot be decided till the Spiti collections have been worked out in detail: for this purpose, they have, as already stated, been sent to Professor Diener, who has kindly informed the author that he believes the provisional correlation of this horizon with the Zewán beds to be correct. Those beds have been regarded by both Waagen

¹ General Report, G. S. I., 1899-1900, p. 189.

² Quart. Journ. Geol. Soc., vol. XXII (1866), p. 29; Journ. As. Soc. Beng., vol. XXXV, p. 128, vol. XXXVI, p. 208; Memoirs, G. S. I., vol. XXII, p. 132; Pal. Indica, ser. XV, vol. I, pt. 2.

and Diener¹ as of upper carboniferous age, and should this correlation be correct, the age of the Fenestella shales should also be upper carboniferous.

On the ridge behind (north-east of) Po, the beds are, as already stated, greatly disturbed and faulted, and the Fenestella shales are only separated from the calcareous sandstone (No. 4, p. 46) by a small thickness of shale and quartzite, the greater part of the conglomerate series having been cut out. Further east, however, towards Thábo, a complete, though slightly faulted, section of the overlying beds is seen in the hills above Lanjarse E. G. Here the Fenestella shales are overlain by thick beds of white and brownish quartzite with equally thick beds of shale. At about 300 feet above the Fenestella shales a band of shale contains fragments of brachiopods and bivalves, but all too badly preserved for determination. The lower shales are usually very fine-grained and argillaceous, but towards the top of the series, where quartzite bands are more numerous, they become siliceous and gritty and occasionally contain thin pebble-beds; higher up the shales disappear altogether and are replaced by quartzites, grits and conglomerates.

As might be expected in shallow-water deposits of this nature, the Permian conglomerate series varies both in character and thickness. High up on the slopes between Lanjarse and Po the shales contain, near their upper limit, beds of grit and a coarse conglomerate; the latter rock forms a bed about 20 feet thick, overlain by another bed of shale, which is followed by a great thickness of grit, quartzite and conglomerate.

South of Pomarang, on the right side of the Spiti river, the sequence is very similar to that just described. The grits are both coarse and fine, and are composed of angular and rounded fragments of shale and limestone embedded in a coarse, slaty matrix. Similarly the conglomerates are composed of boulders and pebbles of various sizes embedded in a gritty or, at times, a slaty matrix, the rock, when crushed,

¹ Pal. Indica, ser. XV, vol. I, pt. 2, pp. 91, 94.

resembling a slate with embedded boulders of all sizes, ranging up to nearly a foot in diameter. This character is particularly noticeable along the path between Pomarang and Máni on the right side of the river, and also between Po and Dankhar, on the left bank, at a short distance below the point at which the path first begins to ascend on to the mesozoic beds; this locality is mentioned by General McMahon, who correlated the conglomerate with the Blaini boulder-slate of Simla.¹ The same rock crops out again at the junction of the Lingti and Spiti rivers,² where it was subsequently examined by Mr. Oldham,³ who also adopted General McMahon's correlation with the Blaini rock.⁴

It has already been stated that the uppermost beds of the palæozoic group consist of a bed of calcareous sandstone overlain by black shales, and that the two beds are seen in all sections, resting at times on the lower silurian quartzite or the upper silurian limestone, as in the Thanam valley; at times on the carboniferous limestone, as in the Pin valley; or underlain, as in lower and upper Spiti and Kanaur, by the conglomerates just described (see Pl. III, fig. 3). The lower part of the calcareous sandstone is coarse and conglomeratic, but the thickness of the conglomerate is often only a few feet. The sandstone is everywhere fossiliferous, but the fossils are usually badly preserved. The collections made from this bed were also sent to Dr. Diener, who has kindly furnished the author with the following list of brachiopods found among them:—

Spirifer fasciger, Keyserling (= *Sp. musakheylensis*, Dav.).

„ *nitiensis*, Diener.

„ *marcoui*, Waagen.

„ *distefanii*, Gemmellaro.

Spirigera gerardi, Diener.

Dielasma la Touchei, Diener (n. sp.).

Streptorhynchus cf. *pectiniformis*, Dav.

Aulosteges cf. *gigas*, Netsch.

¹ Records, G. S. I., vol. XII, p. 63.

² *Ibid.*, p. 64.

³ Records, G. S. I., vol. XXI, p. 151.

⁴ See below, chapter VIII.

Throughout Spiti and Bashahr the calcareous sandstone is invariably overlain by a bed, usually from 100 to 150 feet thick, of black or dark brown, often siliceous, shale, with a few thin bands of hard, brown concretionary sandstone near its base. This bed constitutes the "Productus shales," which extend, with little variation, throughout the entire length of the Himálayas from the Nepál frontier to Kashmir.

When first noticed by Stoliczka in Spiti, these shales were named the "Kuling shales," from the village of Kuling, on the Pin river, where they are well exposed and highly fossiliferous. Stoliczka's nomenclature was adopted by Lydekker in Kashmir, but the term was subsequently rejected by Mr. Griesbach, who substituted the name "Productus shales," and since this term has now been so generally adopted and, owing to the large number of *Producti* always found in the shales, is particularly appropriate, it has also been employed in the present memoir, but Stoliczka's original section at Kuling may still be retained as the type for this part of the Himálayas.

An excellent section is seen on the small ridge behind the village, where the calcareous sandstone (Stoliczka's "quartzite") is overlain by about 150 feet of dark shale, with a few irregular sandstone partings. Above the watercourse which supplies the village, the shales, dipping into the hill, form a steep slope and, near the base of a small cliff which caps the ridge, are overlain by a narrow band of hard ferruginous limestone succeeded by thin alternating beds of shale and limestone; the ferruginous limestone includes Griesbach's "Otoceras beds," which were regarded by him as either of lower triassic age or as permo-trias passage-beds. The underlying shales constitute Stoliczka's "Kuling shales," for which the term "Productus shales" is now substituted.

The limits of this bed are everywhere clearly marked, and the "Productus shales" of Spiti and Bashahr may be defined as a band of dark shale with irregular sandstone partings, included between the top of the fossiliferous calcareous sandstone and the ferruginous limestone containing the zone of *Otoceras woodwardi*, Griesbach.

By the employment of the term "Productus shales," restricted as above, the confusion that has hitherto prevailed with regard to the "Kuling series" will be avoided, for Stoliczka included in that series the beds lying between the Muth quartzite and the triassic limestone, and it should consequently embrace the whole of the carboniferous limestone of Lio in Kanaur, as well as the overlying shales and quartzites of lower Spiti, and since the shales of the Po series are often lithologically indistinguishable from the "Productus shales," the retention of Stoliczka's nomenclature would inevitably lead to confusion.

Throughout Spiti and Bashahr the Productus shales are highly fossiliferous, more especially in the lower part of the series, where numerous brachiopods occur, both in the shale and in the sandstone partings. Although individuals are numerous, only a few species are represented; these include—

Marginifera himalayensis, Diener.

Spirifer rajah, Salter.

„ *fasciger*, Keyserling.

Chonetes lissarensis, Diener.

Productus cf. *gangeticus*, Diener.

Spirigera gerardi, Diener.

Numerous concretions occur, both isolated and in bands, throughout the shale, but they rarely contain fossils. In the upper part of the bed, however, about 30 feet below the top, is a band of concretions containing *Ammonoidea*, which consist chiefly of *Xenaspis* cf. *carbonaria*, Waagen, and *Cyclolobus* cf. *oldhami*, Waagen.¹

In addition to the above fossils, a few *Bryozoa* and badly preserved plants have been found.

¹ The collections which have now been described by Professor Diener, comprise several new species, including—

Cyclolobus insignis.

„ (*Krafftoceras*) *krafftii*.

„ („) *haydeni*.

The characters of the *Productus* shales and the underlying calcareous sandstone are so constant throughout Spiti and Bashahr that descriptions of other sections would be superfluous.

With regard to their age, their position immediately below
 Age of *Productus* shales. triassic beds, as well as their similarity to the permian beds of Painkhanda and Johár, prove that the *Productus* shales of Spiti should be included in the permian system, while their intimate connection, both stratigraphically and palæontologically, with the underlying calcareous sandstone, favour the inclusion of the latter in the same system, but where the base of that system lies cannot be decided till the Spiti collections have been worked out in detail. For the present, it is only possible to say that the *Productus* shales are certainly permian and the calcareous sandstone and conglomerate series almost certainly so.

In the Salt Range *Xenaspis carbonaria* and *Cyclolobus oldhami* were described by Waagen from the upper *Productus* limestone, but more recently Dr. Noetling has placed the zone of *X. carbonaria* in the upper part of the middle *Productus* limestone and that of *Cyclolobus oldhami* considerably higher up, in the upper *Productus* limestone. Waagen's original specimens of these two species were obtained from the same band in the upper *Productus* limestone,¹ and hence this zone may not improbably correspond with the zone of *Xenaspis* cf. *carbonaria* and *Cyclolobus* cf. *oldhami* in the *Productus* shales of Spiti. The lower part of the *Productus* shales would therefore correspond in part to the lower part of the upper *Productus* limestone and probably also to part of the middle *Productus* limestone.

The underlying calcareous sandstone has been correlated by Dr. Noetling with the middle *Productus* limestone of the Salt Range.²

The following table taken from a more comprehensive one prepared by Dr. Noetling³ shows the correlation adopted by him:—

¹ Pal. Indica, ser. XIII, vol. I, p. 25.

² Neues Jahrbuch für Min., etc., vol. XIV, 1901, p. 444.

³ *Ibid.*, opposite p. 468.

				SALT RANGE	SPITI
Trias	Seythian (Buntsandstein)	Upper	Upper ceratite limestone	Zone of <i>Stephanites superbus</i>	Not yet recognised.
			Ceratite sandstone	" <i>Flemingites flemingianus</i>	"Hedenstræmia beds"
		Middle	Ceratite marl	" <i>Koninckites volutus</i>	
				" <i>Prionolobus rotundatus.</i>	Zone of <i>Meekoceras lilangense.</i>
		Lower	Lower ceratite limestone	" <i>Celtites</i> sp.	
Permian	Thuringian (Zechstein)	Upper	Chideru group, or upper Productus limestone	Zone of <i>Euphemus indicus</i>	Zone of <i>Ophiceras tibeticum</i>
				" <i>Medlicottia wynnei</i>	Zone of <i>Otoceras woodwardi</i>
				" <i>Bellerophon impressus</i>	
				" <i>Cyclolobus oldhami</i> " <i>Derbyia hemisphærica</i> " <i>Productus lineatus</i>	Dark shales with <i>Cyclolobus oldhami</i>
		Middle	Virgal group, or middle Productus limestone	" <i>Xenodiscus carbonarius</i>	Dark shales with <i>Xenodiscus carbonarius</i>
				" <i>Lyttonia nobilis</i> " <i>Fusulina kattaensis</i>	Calcareous sandstone with <i>Spirifer musakheylensis</i>
		Lower	Amb group, or lower Productus limestone	" <i>Spirifer marcoui.</i>	Conglomerate and sandstones

It will be noticed that the calcareous sandstone of Spiti* has been correlated with the lower zones of the middle Productus limestone; the fossils obtained from this bed in Spiti are, however, hardly suffi-

ciently numerous or sufficiently characteristic to warrant any exact correlation.

The overlying beds (the *Productus* shales) have been represented by Dr. Noetling as containing two distinct cephalopod zones in Spiti, *viz.*, a lower with *Xenaspis carbonaria*, and an upper with *Cyclolobus oldhami*. This subdivision is apparently due to some slight misapprehension, for, so far as is known at present, there is one and only one ammonite-bearing zone in the *Productus* shales, and this is situated about 30 feet below the top. All the ammonites hitherto found occur in this one zone, which consists of a string of concretions, and its total thickness is not more than one foot.

It has already been stated that the *Productus* shales and calcareous sandstone are found in all permian sections in Spiti and Bashahr, but the underlying beds down to the lowest beds of the carboniferous (or devonian) limestone are very frequently absent, nor are they known to occur in any other part of the Himálayas. In lower Spiti, and again at the head of the Spiti river, they are found in their fullest development, and in both areas the carboniferous limestone and the *Fenestella* shales have been found. The *Fenestella* shales are well exposed in the hills behind Losar.

Judging from the manner in which the younger palæozoic beds thicken out again in upper Spiti, it is probable that they will be found also to the north, in the valley of the upper Chandra river in Lahaul and in Kashmir.

Probable representatives of the Po series in Kashmir.

In fact, a great area has been mapped by Mr. Lydekker in that area as "Panjál", but from his descriptions of that system, it is possible that it may include a considerable part of the shale and quartzite series now known to be most probably of upper carboniferous age. The slates, quartzites and sandstones described by him,¹ as exposed on the southern side of "the Lingti valley, one of the tributaries of the Tsárap valley" appear to correspond so closely in character with the Po series, that they are possibly merely its northern continuation. Further to the

¹ Memoirs, G. S. I., vol. XXII. p. 171.

east, the series is certainly continuous under the high mesozoic ranges north of the Spiti river between Po and Changrizang, and is seen again in Rupshu, where, however, the rocks have been greatly affected by contact- and dynamo-metamorphism.

The lower carboniferous limestones are not known to occur in Kashmir,¹ the only limestones referred by Lydekker to that system being the Zewán beds described originally by Godwin Austen.² These beds are now generally regarded as not older than upper carboniferous, and they cannot therefore correspond with those of the Lipak river. It seems possible, however, that lower carboniferous limestones may occur in Kashmir, for certain sections described by Lydekker, in which slates and quartzites are found overlying limestones, distinctly recall the carboniferous beds of lower Spiti; in most cases, however, Lydekker looks upon the slates and quartzites as members of his Panjál system and consequently assumes that the section is inverted, and that the limestone belongs to his "Supra-kuling series." The true relations can only be determined by a careful and detailed survey, but the question is one of great interest, and the probabilities are certainly in favour of the existence of lower carboniferous beds in Kashmir.

The following table shows the subdivisions of the younger palæozoic systems of Spiti and Bashahr :—

¹ Except in Rupshu : see below, p. 93.

² Quart. Journ. Geol. Soc., vol. XX, p. 383, vol. XXII, p. 29.

PERMIAN			Kanaur (Lipak river), upper and lower Spiti (Losar and Po)	Pin valley, southern and central Spiti
		"Productus shales"	Black shales with <i>Xenaspis</i> and <i>Cyclolobus</i> above, and <i>Marginifera himālayensis</i> below	Black shales with <i>Xenaspis</i> and <i>Cyclolobus</i> above, and <i>Marginifera himālayensis</i> below
			Calcareous sandstone with <i>Spirifer fasciger</i> , <i>Spirifer marcoui</i> , etc.	Calcareous sandstone with <i>Spirifer fasciger</i> , <i>Spirifer marcoui</i> , etc.
			Grit, quartzite and conglomerate.	
CARBONIFEROUS	(?) UPPER	"Po series"	Quartzite and shale ("Fenestella shales")	Unconformity
			Quartzite and shale, with Culm plants	
	LOWER	"Lipak series"	Limestone and thin bands of shale with <i>Syringothyris cuspidata</i> , <i>Productus cora</i> , etc.	Grey limestone, with <i>Syringothyris cuspidata</i>
(?) DEVONIAN			Shaly limestone, with (?) <i>Streptorhynchus umbraculum</i> (?) <i>Atrypa aspera</i>	Flaggy limestone and sandstone

CHAPTER V.

MESOZOIC GROUP.

During the summer of 1898 the lower trias of Spiti was examined in detail by the present writer, and large collections of fossils were made: at the same time the upper triassic beds were also examined, but only somewhat cursorily, and collections were made from only a few horizons. In the following year the writer was accompanied by the late Dr. von Krafft, whose extensive knowledge of triassic fossils rendered him specially suited to the study of the great complex of triassic rocks of Spiti, and it was therefore arranged that he should confine his attention chiefly to the mesozoic beds, while the present writer undertook the palæozoic systems. By this arrangement it was hoped that it might be possible to give a comprehensive and fairly detailed account of the stratigraphy of Spiti, but owing to the sudden death of Dr. von Krafft, the whole work has devolved upon the writer, and since it was found impossible at present to devote another season to field work, the following account of the mesozoic systems has been based on the somewhat scattered notes made by him and on the materials left by the late Dr. von Krafft, from which the greater part of the present chapter has been compiled. At the same time the progress reports published by Dr. von Krafft in the Annual Reports¹ of this department have been largely drawn on, and the work must in the main be looked upon as his.

Triassic System.

LOWER TRIAS.

Although the supposed existence of lower triassic beds in Spiti had been recorded as early as 1865,² no section
 Previous observers. had been described in detail from any part of the

¹ General Report, G. S. I., 1899-1900 and 1900-1901.

² C. W. Gümbel: "Ueber das Vorkommen von unteren Triassschichten in Hochasien"; Sitz k. k. Akad. d. Wiss., 1865.

Himálayas until many years later, when the remarkable discovery by Mr. Griesbach of a complete passage from permian to trias in the mountains of Kumaon and Garhwál completely revolutionised existing ideas on the subject of Himálayan stratigraphy. Stoliczka, too, had previously found, in South Karnág beds that he regarded as of

lower triassic age, but he apparently obtained
 STOLICZKA. no fossils from them, and he overlooked the fossiliferous horizons at the base of the trias in Spiti. The section described in greatest detail by him is that seen behind Kuling, where, according to his description, the *Productus* shales are immediately overlain by beds with *Daonella lommeli*.¹ This statement was due to the fact that his observations were made on an imperfect section found low down on the left side of the small stream which runs between Kuling and Kungri. Here the lower trias and muschelkalk have been cut out by a fault, and the section is exactly in accordance with his description, but a little further to the east, on the higher part of the ridge, the whole of the lower trias is found in its normal position.

By Mr. Griesbach the base of the trias was assumed to lie at the top of the *Productus* shales, which, in all normal
 GRIESBACH. sections in Spiti are overlain by a series of thin alternating beds of limestone and shale. The following subdivision of the lower trias will be found in his memoir (Mem., G. S. I., vol. XXIII, p. 220):—

11.	{	Light-grey limestone; <i>Ptychites gerardi</i> , and other muschelkalk forms	}	Lower.
		<i>Brachiopod</i> limestone		
10.		<i>Otoceras</i> beds (passage-beds)		trias.

The beds containing *Otoceras* were regarded by him as either of lower triassic age² or as permo-trias passage-beds.³ Between these and the “*Brachiopod* limestone” there is a considerable thickness of thin-bedded limestone and shale, containing fossils; no special name

¹ Memoirs, G. S. I., vol. V, p. 345.

² Records, G. S. I., vol. XIII, p. 103; Memoirs, G. S. I., vol. XXIII, pp. 174, 177, 219.

³ Records, G. S. I., vol. XXII, p. 166; Memoirs, G. S. I., vol. XXIII, pp. 68, 219, 223.

was given by him to these beds, but they were recognised as a separate subdivision.¹

In the following table will be found the subdivision and correlation of the lower trias as adopted in the present memoir :—

Concretionary limestone with shaly partings, with <i>Ptychites rugifer</i> <i>Ceratites thuillieri</i> , etc.	UPPER	MUSCHELKALK
Shale with <i>Spiriferina stracheyi</i> <i>Spirigera stoliczkai</i> , etc.	LOWER	
Limestone with <i>Sibirites prahlada</i> <i>Ceratites subrobustus</i> , etc.		
Nodular limestone	HEDEN- STRÆMIA BEDS	LOWER TRIAS
Shale with <i>Rhynchonella griesbachi</i>		
Limestone with <i>Pseudomonotis himaica</i>		
Limestone and shale with <i>Hedenstræmia mojsisovicsi</i> <i>Flemingites rohilla</i> , etc.		
Limestone with <i>Meekoceras</i> .		
Limestone with <i>Ophiceras</i> .		
Limestone with <i>Otoceras</i> .		

¹ Memoirs, G. S. I., vol. XXIII, p. 70.

In 1891, the *Otoceras* beds (Griesbach) were included by the late Dr. Waagen¹ in the permian system, but were accepted as passage-beds and correlated with the Djulfa beds and with the Chideru and overlying unfossiliferous beds of the Salt Range; in a subsequent paper,² however, he placed them in the Scythian series of the triassic system.

The beds between the top of the *Productus* shales and the horizon of *Rhynchonella griesbachi* were subsequently "Otoceras beds," divided by Diener³ into the "Otoceras beds" and "Subrobustus beds," the former name being applied to the lower part of the series. Further detailed study of the numerous sections in Spiti has shown that the genus *Otoceras* is apparently confined to a narrow band of limestone, only a few inches in thickness, occurring at the base of the series, and the lower beds have been found by Dr. Noetling in Niti and by Dr. von Krafft in Spiti to contain three distinct zones, each characterised by the predominance of a single genus of ammonite. The two lower zones have been referred by Dr. Noetling to the permian system.⁴

The three zones are, in descending order,—

(3) *Meekoceras* zone—

Thin, concretionary limestones, alternating with thin layers of shale, and containing large numbers of *Meekoceras* . 3 ft.
The fossils include

Meekoceras varaha, Diener.

„ many new species.

Proptychites ammonoides, Waagen.

„ *markhami*, Diener.

Clypites n. sp.

(2) *Ophiceras* zone—

Grey limestone 1 ft. 5 ins.

full of *Ophiceras sakuntala*, Diener, and containing also

Meekoceras varaha, Diener.

Pseudomonotis griesbachi, Bittner.

(1a) Brown, sandy limestone, apparently unfossiliferous . 1 ft. 7 ins.

¹ Pal. Indica, ser. XIII, vol. IV, pt. 2, Table of Strata, opp. p. 238.

² Sitzungsber. d. k. Akad. Wien, CIV, pt. 1, 1895, pp. 1278 sqq.

³ Denkschrift der k. Akad. Wien, Bd. LXII, 1895, pp. 533—608.

⁴ Neues Jahrbuch für Min., etc., XIV, 1901, p. 467.

(1) *Otoceras* zone—

Hard, ferruginous limestone	5 ins.
with <i>Otoceras woodwardi</i> , Griesbach.	
„ <i>clivei</i> , Diener.	
„ n. sp.	

It was at first supposed by Dr. von Krafft that bed No. 2 was that in which *Otoceras* occurred, although no specimens of that genus were found by him in Spiti. It had, however, already been obtained by the present writer from the lowest horizon, and was subsequently found in the same bed by Dr. von Krafft in other parts of the Himálayas. He therefore adopted the above subdivision of Diener's "*Otoceras* beds." The lowest or *Otoceras* zone can

Otoceras zone. now be almost certainly correlated with the "main layer of *Otoceras woodwardi*" of Kumaon and Garhwál. From this horizon Professor Diener obtained one specimen of *Medlicottia dalailamæ*, Diener,¹ while from the shales immediately overlying this "main layer" another specimen was collected by Mr. Griesbach. A comparison of these specimens with *Medlicottia wyneei*, Waagen, from the Chideru beds of the Salt Range, led Dr. von Krafft to the conclusion that the two species were identical,² and he therefore correlated the Chideru beds with the *Otoceras* zone of the Himálayas, thereby giving support to Dr. Noetling's opinion as to the permian age of the *Otoceras* zone. At the same time, it should be noted that Professor Diener refuses to admit the identity of the two forms,³ and the question cannot, therefore, be considered as beyond dispute.

At the end of the last chapter Dr. Noetling's table of correlations of the Salt Range horizons with those of the Himálayas has been partly reproduced⁴: from this it will be seen that he places the *Otoceras* zone even lower in the series than did Dr. von Krafft, and correlates the overlying zone (*Ophiceras* zone) with the zones of *Medlicottia wyneei* and *Euphemus indi-*

¹ Pal. Indica, ser. XV, vol. II, pt. 1, p. 59.

² Centralblatt für Min., etc., No. 9, 1901, p. 275.

³ *Ibid.*, No. 17, 1901, p. 513.

⁴ *Supra*, p. 56.

cus, and the Meekoceras zone with the zone of *Prionolobus rotundatus* and *Celtites* sp. With regard to the Meekoceras zone, Dr. von Krafft

stated, in the paper quoted above, that it certainly belonged to the lower trias, while he left the age of the Ophiceras zone doubtful, having no proof of either a permian or a triassic age. On the other hand, Dr. Noetling has correlated the latter zone with the uppermost permian, on account of the supposed absence of the genus *Meekoceras*¹; but, as will be seen from the list of fossils already given, that genus has been found in the Ophiceras zone in Spiti, and any attempt at correlation on this ground with the zones of *Medlicottia wynnei* and *Euphemus indicus* therefore fails.

It would perhaps seem unnecessary to discuss this question in such detail in the present memoir, but it has been deemed advisable to indicate as briefly as possible the present state of the discussion, which may be summed up as follows :—

The Meekoceras zone has been unanimously referred to the lower trias: the age of the Ophiceras zone was looked upon as doubtful by Dr. von Krafft, while the reason given by Dr. Noetling for placing it in the permian system is not valid for Spiti; with regard to the Otoceras zone, a strong case in favour of its permian age has been made out by Dr. von Krafft in the supposed identity of *Medlicottia wynnei*, Waagen, with *M. dalailamæ*, Diener. This question of identity or otherwise can be decided only by specialists, and as it still remains a matter of dispute, it has seemed preferable in the present memoir to describe the zone in connexion with the series to which it belongs *lithologically*, leaving its age an open question. As already stated, it was regarded by Mr. Griesbach as a passage-bed between the permian and trias, and until many more sections in the Himálayas have been worked out in detail, it is unlikely that we shall be able to assign it definitely to one system or the other.

Above the Meekoceras zone there is an alternating serie of thin-

¹ *Op. cit.*, p. 466.

bedded limestone and shale, having a total thickness of about 34 feet. This is the equivalent of the greater part of Diener's "Subrobustus beds" of the Kumaon Himálayas. In the present memoir this term will not be employed, for *Ceratites subrobustus*, Mojs., has not been found in these beds in Spiti, but occurs at a considerably higher horizon; the name "Hedenstræmia beds," suggested by Dr. von Krafft, will therefore be substituted.

The lower part of the series consists of a band of hard limestones, weathering brown; it is about 4 feet thick, and contains few fossils, which are badly preserved but appear to include *Flemingites* sp. Owing to the absence of fossils, it is uncertain whether this band should or should not be included in the Hedenstræmia beds. It is overlain by thin-bedded limestone, with narrow partings of shale, having a total thickness of about 30 feet, and containing numerous lower triassic fossils, which include—

- Danubites nivalis*, Diener.
- „ *purusha*, Diener.
- „ *kapila*, Diener.
- Hedenstræmia mojsisovicsi*, Diener.
- Flemingites rohilla*, Diener.
- „ cf. *salya*, Diener.
- Aspidites superbus*, Waagen.
- Koninckites yudisthira*, Diener.

The above series constitutes the "Hedenstræmia beds" in the sense in which the term was employed by Dr. von Krafft. Ammonites occur throughout the series, which is overlain by lithologically similar beds of limestone and shale having a thickness of about 6 feet. Two fossiliferous horizons occur in these beds; the lower horizon has yielded large numbers of bivalves, which consist almost entirely of *Pseudomonotis* (? *Avicula*) *himaica*, Bittner, and *Pseudomonotis decidens*, Bittner.

The upper horizon, which is a calcareous shale or shaly limestone, occurs 6 feet higher up and contains brachio-
 Horizon of *Rhynchonella griesbachi*. pods, including *Rhynchonella griesbachi*, Bittner, and *Retzia himaica*, Bittner.

This horizon, which has hitherto been regarded as the base of the muschelkalk, is overlain by a bed, about 60 feet thick, of hard, nodular limestone, containing hardly any fossils, those which occur being usually too badly preserved for determination.

In his paper already quoted Professor Diener states¹ that in addition to the species mentioned above, the beds with *Rhynchonella griesbachi* had yielded also the following forms (determined by the late Dr. A. Bittner²):—

Boundary between
lower trias and mus-
chelkalk.

Spiriferina stracheyi, Salter.

Retsia n. sp. (= *R. himaica*, Bittner).

Spirigera, n. sp. (= *S. stoliczkai*, Bittner).

Although the band with *Spiriferina stracheyi* is very well developed and highly fossiliferous in all muschelkalk sections in Spiti, yet in spite of most careful search, neither Dr. von Krafft nor the present writer could find in it any trace of *Rhynchonella griesbachi*, but subsequently the latter species was found by Dr. von Krafft in Kumaon in the bed immediately below the nodular limestone; the two brachiopod-bearing horizons being thus separated from one another by a vertical distance of about 70 feet.

The horizon of *Rhynchonella griesbachi* not having been previously recognised in Spiti, a careful search was made during the last field season, with the result that it was found in the same position as in Kumaon, that is to say, below the nodular limestone. At the same time the true position of the horizon of *Pseudomonotis himaica* was also determined. While collecting from the horizon of *Rhynchonella griesbachi*, the present writer found, both in and above it, several poorly preserved fragments of ammonites, which appeared to resemble lower triassic species; these were submitted to Dr. von Krafft, but they were in most cases too badly preserved to admit of determination. A

¹ Denkschrift. der k. Akad., Wien, LXII, 1895, p. 571.

² Pal. Indica, ser. XV, vol. III, pt. 2.

few, however, were determinable: these were derived from two horizons—

(a) six inches above the top of the bed with *Rhynchonella griesbachi*; and

(b) middle of the nodular limestone, i.e., about 30 feet above the horizon of *Rhynchonella griesbachi*.

The specimens from (a) include—

Tirolites n. sp.¹

(?) *Dinarites* sp. ind.

The first of these forms had hitherto been found only in the lower trias, having been obtained from the Hedenstræmia beds near Muth.

Horizon (b) yielded—

Ceratites n. sp., identical with a form previously obtained from the Hedenstræmia beds at Muth; and

Nannites n. sp. ind.

With regard to these discoveries it will be advisable to quote Dr. von Krafft's own words, from a letter written by him to the present writer, shortly before his death: "It is clear that the horizon of *Rhynchonella griesbachi*, looked upon by Diener, Griesbach, Bittner and myself as lower muschelkalk, must be included in the lower trias, and so must at least half of the nodular limestone. The genus *Tirolites* is in Europe known from the lower trias only: the species from the base of the nodular limestone is, moreover, identical with a type from the 'Subrobustus beds' (Diener). The occurrence of *Ceratites* n. sp. in the middle of the nodular limestone only corroborates this conclusion. The boundary between the lower trias and the muschelkalk is therefore much more accurately fixed than it was before, and must lie either within the nodular limestone or at the base of the beds with *Spiriferina stracheyi*. The former is, I think, more probable, because I remember having found lower muschelkalk types in the top-most beds of the nodular limestone."

¹ A description of this species, which he named *T. injucundus*, has been left among Dr. von Krafft's descriptions of lower trias ammonites, which it is hoped will be published shortly.

In view of the above, the upper boundary of the lower trias will lie somewhat higher than has hitherto been supposed, and must be taken somewhere above the middle of the nodular limestone. Plate IV represents a section of the lower and middle trias in the hills to the south-east of Muth. A comparison of this figure with that to be found on page 546 of Professor Diener's account of his expedition to the Himálayas in 1892¹ will show that the lithological succession of this part of the trias of Spiti is almost identical with that of Painkhanda, but the interpretation given above of the Spiti sequence differs from that given by Professor Diener for the Shalshal cliff.

The *Productus* shales, *Otoceras* beds and *Hedenstræmia* beds—Diener's "*Subrobustus* beds" in part—are the same in both sections while his "*Subrobustus* beds" include the horizon of *Pseudomonotis himaica*, which fossil was first discovered by him in the Shalshal cliff.

His subdivision (4), which he names the "horizon of *Sibirites prahlada*," is said by him to contain also *Rhynchonella griesbachi* and *Spiriferina stracheyi*, but this association of the two last-named brachiopods was considered by Bittner as highly improbable.² These doubts were subsequently confirmed by Dr. von Krafft, who had an opportunity of studying Diener's original section on the spot: he found that the section was in every respect similar to those of Spiti, and that there were two brachiopod-bearing horizons, *viz.*, that of *Spiriferina stracheyi* above, and that of *Rhynchonella griesbachi* below, the nodular limestone, nor could he find in the lower horizon any trace of the brachiopods so common in the upper, while the horizon of *Spiriferina stracheyi* was found to correspond in every respect with the same horizon in Spiti. At that time the lower horizon had not been detected in Spiti, and on Dr. von Krafft's suggestion the present writer made a careful search for it and succeeded in finding it at the base of the nodular limestone, in the exact position in which it was found by Dr. von Krafft at the Shalshal cliff; in Spiti, however, it is poorly developed and fossils are scarce, and it had consequently been previously overlooked.

¹ Denkschrift. der k. Akad., Wien, LXII, 1895.

² Jahrbuch k. k. Geol. Reichsanstalt, XLVIII, 1899, p. 692.

As already implied, Dr. von Krafft also found the nodular limestone of Spiti represented in the Shalshal section by an exactly similar bed: this is No. 5 of Diener's section, hence his horizons (4) and (5) will correspond respectively with the horizon of *Rhynchonella griesbachi* and the nodular limestone of Spiti.

MIDDLE TRIAS.

As stated above, the upper boundary of the lower trias, which had hitherto been drawn at the base of the horizon of *Rhynchonella griesbachi* must now be placed somewhat higher up, at, or above, the middle of the nodular limestone. At present our knowledge of this bed is so small, and its fossil contents so few and so badly preserved, that no more accurate delimitation is possible.

The following subdivisions constitute the middle trias of Spiti:—

Daonella	lime-	Hard, black limestone, with <i>Daonella lommeli</i> , Wissm.	145 ft.
Daonella	shales	Black, thin-bedded and flaggy limestone, with greyish-black calcareous and earthy shales, containing <i>Daonella lommeli</i> and cephalo- pods	160 ft.
MUSCHELKALK	Upper	Dark, concretionary limestone, with thin beds of dark shale, containing <i>Ptychites gerardi</i> , Blanf.	20 ft.
	Lower	Grey limestone with <i>Xenaspis</i> sp. and <i>Ceratites</i> aff. <i>ravana</i> , Diener	1 ft. 4 ins.
		Grey concretionary limestone	6 ins.
		Grey shaly limestone, with <i>Spiriferina stra-</i> <i>cheyi</i> , Salt.	4 ins.
		Grey limestone	3 ins.
		Hard, dark grey limestone, with <i>Ceratites</i> <i>subrobustus</i> , Mojs., and <i>Sibirites prahlada</i> , Diener	4 ins.
		Thin-bedded, grey limestone and shale	3 ft.
		Upper part of nodular limestone	

MUSCHELKALK.

The nodular limestone is overlain by thin beds of limestone and shale, containing badly preserved cephalopods, none of which have been determined. Above this is a narrow band of limestone, in which are numerous well-preserved fossils. They include—

Ceratites subrobustus, Mojs.
Monophyllites confucii, Diener.
 „ *pitamaha*, Diener.
Sibirites prahlada, Diener.
Gymnites ugra, Diener.
Danubites kansa, Diener.
Hungarites sp.

This bed has been traced throughout Spiti and Bashahr, but is particularly well seen in the upper Thanam valley and near Tanga Chenmo in the valley of the Gyundi river.

A few inches higher up is a band of shaly limestone or calcareous shale, containing the characteristic fossils of the horizon of *Spiriferina stracheyi*, viz.:—

Spiriferina stracheyi, Salter.
Spirigera stoliczkai, Bittner.
Terebratula himalayana, Bittner.
Rhynchonella mutabilis, Stol.

The discovery of these two horizons in one and the same section is one of considerable importance, for the cephalopod fauna with *Ceratites subrobustus* contains a large number of species which had hitherto been found only in the detached and isolated blocks (so-called *klippen*) of Chitichun, and were described by Diener,¹ who believed them to be of lower muschelkalk age.

It was at first supposed that the cephalopod and the brachiopod horizons were separate and distinct, but it was subsequently found by Dr. von Krafft that brachiopods occur also with the cephalopods and the two probably constitute one horizon, in the lower part of

¹ Pal. Indica, ser. XV, vol. II, pt. 2, pp. 101--118.

which cephalopods predominate, and in the upper, brachiopods.¹ This single horizon would then correspond to Diener's "horizon of *Sibirites prahlada*" of the Shalshal cliff, which, however, should be placed above and not, as represented in his section, below the nodular limestone (see Pl. IV).

Above the horizon of *Spiriferina stracheyi* a band of limestone about two feet thick, contains *Xenaspis* sp. and *Ceratites* aff. *ravana*, Diener. This probably forms the highest horizon of the lower muschelkalk; it is overlain by the mass of limestone and shale which constitutes the upper muschelkalk and which contains a very rich fauna, including over 65 species of *Ammonoidea*. Of these, the most important will be found in the following list:—

- Ceratites voiti*, Oppel.
- „ *ravana*, Diener.
- „ *hidimba*, Diener.
- „ *airavata*, Diener.
- „ *dungara*, Diener.
- „ *vyasa*, Diener.
- „ *thuillieri*, Oppel.
- „ *himalayanus*, Blanford.
- „ *horridus*, Oppel.
- „ sp. ind. aff. *Cer. wetsoni*, Oppel.
- „ aff. *trinodosus*, Mojs.
- „ aff. *superbus*, Mojs.
- „ aff. *abichi*, Mojs.
- „ aff. *kamadeva*, Diener.
- Japonites* (*Danubites*) *dritarashtra*, Diener.
- „ n. sp.
- Trachyceras* aff. *longobardicum*, Mojs.
- Acrochordiceras damesi*, Noetling.
- Isculites hauerinus*, Stol.
- Joannites* aff. *diffissus*, v. Hauer.
- Meekoceras khanikoffi*, Oppel.
- „ aff. *proximum*, Oppel.

¹ Similar beds were subsequently found by Dr. von Krafft in the Bambanag cliff in Painkhanda, where *Spiriferina stracheyi* occurs in the same bed with *Ceratites subrobustus* and *Monophyllites hara*: a full discussion as to the correlation of the trias of Spiti with that of other parts of the Himalayas will be found in Dr. Krafft's paper, which will form part 2 of this volume.

Gymnites jollyanus, Oppel.

„ *kirata*, Diener.

„ *vasantasena*, Diener.

„ *lamarcki*, Oppel.

Buddhaites rama, Diener.

Sturia sansovinii, Mojs.

Proarcestes bicinctus, Mojs.

„ *balfouri*, Mojs.

Hungarites nitiensis, Mojs.

„ n. sp.

Monophyllites sp.

Ptychites rugifer, Oppel.

„ *tibetanus*, Mojs.

„ *mangala*, Diener.

„ *sukra*, Diener.

„ *cognatus*, Oppel.

„ *asura*, Diener.

„ *govinda*, Diener.

„ *impletus*, Diener.

„ *sahadeva*, Diener.

„ *sumitra*, Diener.

„ *gerardi*, Blanf.

„ *everesti*, Oppel.

„ *vidura*, Diener.

„ *drona*, Diener.

„ *cochleatus*, Oppel.

„ *cochleatus* var., Oppel.

„ *mahendra*, Diener.

„ n. sp. ex. aff. *P. malletianus* Stol., Diener.

Nautiloidea also occur, including—

Nautilus cf. *griesbachi*, Diener.

„ *spitiensis*, Stol.

Pleuromutilus sp.

Orthoceras cf. *campanile*, Mojs.

Of *Brachiopoda*, *Spirigera hunica*, Bittner, is common.

In addition to the above species, which were determined by Dr. von Krafft, there are numerous new species which still await description.

The earliest collections of muschelkalk fossils from Spiti were made by the brothers Schlagintweit,¹ by Dr. Gerard² and by

¹ A. Oppel : " Ueber die ostindische fossilreste, etc., " Pal. Mittheilungen, I, p. 267. C. W. Gümbel : " Ueber das vorkommen von unteren Triasschichten in Hochasien, " Sitz. k. k. Akad. d. Wiss, 1865.

² See H. F. Blanford, in Journ. As. Soc. Beng., 1863, No. 2, pp. 124—138.

Stoliczka.¹ Subsequently they were considerably augmented by Mr. Griesbach.

From the list given above it will be seen that there is the closest resemblance between the muschelkalk fauna of Spiti and that of the more easterly parts of the Central Himálayas, almost all the species that have been recorded from the latter having now been found in Spiti.

Throughout Spiti and Bashahr, wherever the middle trias is exposed, good sections with muschelkalk fossils can be found, but the most accessible are those of the Pin valley, *viz.*, that behind the village of Muth, and the section near (N.-N.-W. of) Kágá on the left side of the Parahio; it is from the latter locality that the greater part of the recent collections was derived.

An examination of the collections made from the muschelkalk of Spiti in 1898, led Dr. von Krafft to believe that the ladinic stage of Europe, hitherto supposed to be wanting in the Himalayan trias,² either existed in Spiti as a separate horizon or was included in the upper muschelkalk. At the same time, the presence of this stage in Spiti was inferred by Dr. Bittner³ from a specimen of *Daonella lom-meli*, Wissm., found among the collections entrusted to him for description. Special attention was therefore devoted to this point, and it was found that the ladinic stage was not only present but was very well developed, and that there was a gradual passage between it and the uppermost muschelkalk, several species of ammonites being common to both stages.

The beds representing the ladinic stage fall into two main subdivisions, the lower of which is chiefly composed of shaly beds (*Daonella* shales), while the upper consists of hard, dark, splintery limestones (*Daonella* limestone).

¹ Memoirs, G. S. I., vol. V.

² E. von Mojsisovics: Pal. Indica, ser. XV, vol. III, pt. 1, p. 135. C. Diener: Denkschr. d. k. Akad., Wien, 1895, p. 581.

³ A. Bittner: Pal. Indica, ser. XV, vol. III, pt. 2, p. 38.

The lower beds are thin-bedded, flaggy and shaly limestones with earthy shales and bands of hard, dark limestone ;
 Daonella shales. the thickness of this subdivision is about 160 feet.

Fossils are common near the base of the series ; they include—

- Daonella lommeli*, Wissm.
- „ *indica*, Bittner.
- * *Spirigera hunica*, Bittner.
- * *Proarcestes bicinctus*, Mojs.
- * *Ptychites gerardi*, Blauf.
- * *Hungarites nitiensis*, Mojs.
- „ aff. *mojsisovicsi*, Bœckh.
- * „ n. sp.
- Ceratites* n. sp. aff. *Cer. himalayanus*, Blauf.
- Gymnites ecki*, Mojs.
- Trachyceras ladinum*, Mojs.
- „ aff. *archelaus*, Mojs.

The species marked * have already been recorded from the upper muschelkalk ; from the above list it will be seen that they also occur in association with *Gymnites ecki*, *Trachyceras ladinum*, and other forms characteristic of the ladinic stage of Europe.¹ The ladinic age of this subdivision is further confirmed by the presence of *Daonella lommeli*, Wissm. A single specimen of this fossil was found by the late Dr. Bittner among the collections made by Mr. Griesbach near Muth,² but it was subsequently found to be very common in the so-called “Daonella beds” throughout Spiti and Bashahr.

It is evident, therefore, that no palæontological break occurs in Spiti above the upper muschelkalk, but that the passage into the ladinic stage is so gradual that no boundary line can be fixed between the two.

Forms common to Daonella shales and upper muschelkalk.

Absence of palæontological break in middle trias.

¹ A fuller discussion of this question will be found in the General Report, G. S. I., 1899-1900, pp. 208—213.

² The presence of this species in Spiti had been originally recorded by Stoliczka, but owing to its absence from his collections, doubts were cast by Dr. Bittner on the accuracy of his determination (Pal. Indica, ser. XV, vol. III, pt. 2, p. 34).

In all sections the muschelkalk is overlain by a narrow band, 8 to 12 inches thick, of rotten, splintery and shaly limestone which contains large numbers of *Daonella*, and contains also the *Cephalopoda* mentioned above as occurring also in the underlying main mass of the upper muschelkalk. Immediately above this are the "Daonella shales," with *D. lommeli*.

The lithological characters of this stage are constant throughout Spiti; it consists, as already stated, of two Daonella limestone. divisions, a lower, in which shales predominate (the "Daonella shales"), and an upper composed of hard, dark limestone (the "Daonella limestone"). The latter is about 145 feet thick and contains few fossils, with the exception of *Daonella lommeli*, which is common throughout.

Owing to these lithological characters, the middle trias of Spiti can usually be recognised at a glance, for the nodular limestone forms a low but steep cliff, followed by the less abrupt slopes of the muschelkalk, while the soft Daonella shales form a still gentler slope, capped by a sheer cliff, often two hundred feet or more in height, of the black Daonella limestone, with part of the overlying upper trias limestones.

UPPER TRIAS.

It has been seen that the lower and middle trias of Spiti has yielded a large and representative fauna. Unfortunately the same cannot be said of the upper divisions of the system, our knowledge of which is much less complete. This is due to a large extent to paucity of fossils, but also to the fact that the uppermost beds of the trias consist of hard dolomitic limestones, forming steep, often vertical cliffs, in many sections quite inaccessible and in others accessible only to the practised mountaineer. Nevertheless many of the horizons of the upper trias of Europe can be recognised and have yielded, locally, characteristic and well-preserved fossils.

It was formerly supposed by Dr. von Mojsisovics and by Professor Diener, that the muschelkalk of the Himálayas was immediately overlain by beds representing in part the carnian stage of Europe, but, as

already stated, more recent work in 1898 and 1899 had proved that this was not the case in Spiti, but that beds including the ladinic stage were largely developed. Subsequently Dr. von Krafft, when

Ladinic stage of Europe represented in Painkhanda.

studying the sections of the Kumaon Himálayas, came to the conclusion that the same stage was represented also in the Shalshal cliff, but that the

beds including it were much thinner, being only 25 feet thick as against 300 feet in Spiti.¹ In both areas it is overlain by beds containing fossils found in the carnic stage of Europe. In Spiti these beds fall into the following subdivisions :—

Tropites beds	6. Dolomitic limestone	300 ft.
	5. Dark, splintery limestone, with alternations of grey, shaly limestone and calcareous shale, with <i>Parajuvavites</i> , sp.	200 ft.
	4. Nodular limestone and grey shale, with <i>Clydonautilus griesbachi</i> , Mojs. <i>Tropites</i> cf. <i>subbullatus</i> , v. Hauer. „ cf. <i>discobullatus</i> , Mojs. Species of <i>Juvavites</i> and <i>Sagenites</i> .	15 ft.
	3. Dark, splintery limestone, shaly limestone and calcareous shale	400 ft.
Grey shales	2. Soft, pale grey, calcareous shales, with limestone bands; containing brachiopods above and ammonites below	535 ft.
Halobia beds	1. Hard, dark, splintery limestone, with flaggy and shaly bands with <i>Halobia</i> sp., and <i>Arcestes</i> sp. .	140 ft.

The lowest of the above subdivisions is a continuation of the black Halobia limestone. *Daonella* limestone, but owing to the apparent absence of *Daonella lommeli* in the upper beds and to the presence of *Halobia* either identical with, or very nearly

¹ General Report, G. S. I., 1900-01, p. 27.

allied to, *Halobia comata*, Bittner, and *H. fascigera*, Bittner, it has been considered advisable to separate the *Halobia* beds as a distinct subdivision.

This limestone is overlain by a thick series of soft, grey or pale lavender shales with which thin bands of limestone are intercalated. Almost immediately above the *Halobia* limestone, the shales contain a band of black concretions which enclose numerous ammonites; the fossils are in most cases fragmentary, and only one species has been completely determined: this is

Foannites cymbiformis, Wulf.,

which has been found at this horizon at several localities, in Spiti and also in the Thanam valley in Bashahr. The remaining fossils include—

Trachyceras cf. *aonoides*, Mojs.

„ n. sp. aff. *ariæ*, Mojs.

Hauerites n. sp.

Drepanites n. sp.

Foannites cf. *cymbiformis*, Mojs.

Only one other fossiliferous horizon has been found in the grey shales; it occurs at about 300 feet above the base, and consists of a grey, shaly limestone, containing large numbers of brachiopods, which include—

Spiriferina shalshalensis, Bittner;

Rhynchonella lankana, Bittner;

Discina sp.;

and several other forms not yet determined. One ammonite (*Distichites* sp.) was found by Dr. von Krafft in this bed, while *Megalodon* sp. and other bivalves occur in the upper part of the series.

The brachiopod horizon is overlain by grey shales, about 200 feet thick, similar to those below: thin bands of limestone are intercalated with the shales and become more and more numerous in the upper part of the series, till the formation becomes one of limestone, with subordinate bands of shale: this is subdivision (3) in the above list. Fossils

Brachiopod lime- are rare, but above Muth and near Lilang the
stone. limestone contains at one horizon large numbers
of brachiopods and bivalves, which, however, still await determination,

A little higher in the series a band of nodular limestone with gray shales—subdivision (4)—contains ammonites chiefly belonging to the genus *Tropites*. The fossils are rare and badly preserved, but the following forms were recognised by Dr. von Krafft:—

- Tropites* cf. *subbullatus*, v. Hauer.
 „ cf. *discobullatus*, Mojs.
 „ cf. *fusobullatus*, Mojs.
 „ cf. *torquillus*, Mojs.
Juvavites aff. *bacchus*, Mojs.
 „ sp. ind cf. *J. bacchus*, Mojs.
Sagenites sp. aff. *erinaceus*, Dittmar.
 „ n. sp. aff. *herbichi*, Mojs.
Sandlingites n. sp.
Sirenites n. sp.
 (?) *Heracrites* sp.
Clydonautilus griesbachi, Mojs.
Nautilus sp.

This horizon presumably corresponds to the “*Tropites* limestone” of Kálápani, which is, according to von Mojsisovics, the equivalent of the “zone of *Tropites subbullatus*” of the Mediterranean Province.¹

The nodular limestone with *Tropites* is overlain by a band of dark, splintery limestone about 200 feet thick, with beds of calcareous shale; it has yielded few fossils, but some specimens of *Parajuvavites* n. sp. were found by Dr. von Krafft at about 70 feet above the *Tropites* horizon. One specimen of the same species was found loose on the *Tropites* beds, and as Dr. von Krafft considered it improbable that under the existing circumstances it could have rolled down from a higher horizon, he assumed that it belonged to the horizon at which it was found and consequently included the upper beds, in which the species occurs, in the *Tropites* beds.

The age of the next overlying bed—(6) the dolomitic limestone—
 Dolomite. is doubtful, it having yielded few fossils, and those very badly preserved and fragmentary;

¹ Pal. Indica, ser. XV, vol. III, pt. 1, pp. 154, 155.

among them, however, are some bivalves which were determined by the late Dr. A. Bittner as—

Lima cf. *austriaca*, Bittner.;
Daonella cf. *styriaca*, Mojs.; and
Halobia cf. *superba*, Mojs.

In Europe, *Lima austriaca* occurs in the Opponitz limestone and *Daonella styriaca* and *Halobia superba* in the carnic beds of Aussee.¹

The following sequence is found in Spiti above the Tropites beds:—

5. Black, splintery and earthy limestone and dolomite; with
Megalodon ladakhensis, Bittner.
Dicerocardium himalayense, Stol.
Lima cumaunica, Bittner.
 „ *serraticosta*, Bittner.
 (?) *Spirigera noetlingi*, Bittner.
4. White and brown quartzite, with black shales and grey limestone;
 with 300 ft.
Spirigera n. sp.
Aulacothyris joharensis, Bittner.
Lima cumaunica, Bittner.
Spiriferina griesbachi, Bittner.
3. Brown-weathering shale (calcareous and micaceous) and shaly
 limestone, with some sandstone; with 300 ft.
Spiriferina griesbachi, Bittner.
Rhynchonella bambanagensis, Bittner.
Spirigera dieneri, Bittner.
Aulacothyris joharensis, Bittner.
Monotis salinaria, Bronn.
Anodontophora griesbachi, Bittner.
Distichites n. sp.
2. Coral limestone; with 100 ft.
Spiriferina griesbachi, Bittner.
Rhynchonella bambanagensis, Bittner.
1. Brown-weathering shale, with shaly limestone and sandstone;
 with 500 ft.
Paratibetites cf. *tornquisti*, Mojs.
Fuvavites, cf. *ehrlichi*, Mojs.
Hauerites n. sp. ind.

Above the dolomitic limestone a rapid change takes place in the lithological character of the beds. The compact limestones give place

¹ E. von Mojsisovics: Abhandl. k. . Geol. Reichsanstalt, Wien, Bd. VII, (1894), Heft. 2, pp. 10, 30.

to calcareous shales and shaly limestones, and, with the exception of the bed of coral limestone in the lower part of the series, the rocks consist almost entirely of shales with intercalated bands of sandstone; in fact the series consists broadly of two thick beds of calcareous shale or very shaly limestone, separated by the massive coral limestone and overlain by brown and white quartzites; this group is thus easily recognised on the mountain sides, even at considerable distances.

The lower part of the first shaly series (1) is composed of sandy limestones, passing up into sandstones and calcareous shales which contain, in addition to numerous indeterminate plant remains, a few brachiopods and bivalves with fragments of ammonites, including—

Hauerites sp.

Hauerites (?) n. f. ind., Mojs.¹ and

Paratibetites cf. *ternquisti*, Mojs.

The bivalves include—

Mysidioptera sp.

Avicula sp.

Modiola sp.

Anodontophora griesbachi, Bittner.

This horizon was correlated by Dr. von Krafft with the “Hauerites beds” (Diener) of the more easterly sections of the Himálayas.

The overlying shales contain large numbers of ammonites; they are to a great extent fragmentary, but most of their important characters can still be recognised. By far the commonest genus is *Juvavites*, of which a few forms belong to the groups of “intermittentes” and “scissi,” but the great majority approach the “continui” (Mojsisovics). Other forms represented are

Paratibetites ternquisti, Mojs.

Tibetites cf. *ryalli*, Mojs.

* *Anatibetites* n. sp. aff. *kelvini*, Mojs.

Clionites aff. *hughesi*, Mojs.

Dittmarites n. sp.

Pinacoceras sp.

Phylloceras sp. ind.

Pleuronautilus aff. *tibeticus*, Mojs.

¹ Pal. Indica, ser. XV, vol. III, pt. 1, p. 88.

A few bivalves also occur in the shales; they belong to the genus *Halobia*, and closely resemble *H. fascigera*, Bittner.

It is probable that these "Juvavites shales" correspond to the "Halorites beds" (Diener), from which they differ, however, in the apparent absence of both *Halorites* and *Parajuvavites*, neither of which genera has been found at this horizon in Spiti.

The shales are overlain by a massive, grey—at times white and dolomitic—limestone, chiefly composed of corals.

Coral limestone.

It forms a very characteristic horizon throughout Spiti and Rupshu, but has not been recognised in Kumaon or in Garhwál. The commonest fossil is a coral resembling *Lithodendron*, the presence of which led Mr. Griesbach to regard the limestone as of rhætic age.¹ A few gastropods were found in this bed in Rupshu, and brachiopods in Spiti; the latter are rare, but include—

Spiriferina griesbachi, Bittner; and

(?) *Rhynchonella bambanagensis*, Bittner.

Consequently Dr. von Krafft believed that this limestone represented the "beds with *Spiriferina griesbachi*" of the Painkhandas sections.

The coral limestone is overlain by arenaceous limestones and sandstones, passing up into a series of calcareous shale, which in lithological characters strongly resembles the "Juvavites beds." This subdivision, the thickness of which is about 300 feet, contains an interesting fauna, composed almost entirely of bivalves and brachiopods, which occur chiefly in the upper part of the series: they include—

Monotis shales.

Monotis salinaria, Bronn.

Anodontophora griesbachi, Bittner.

Spiriferina griesbachi, Bittner.

Rhynchonella bambanagensis, Bittner.

Aulacothyris joharensis, Bittner.

Spirigera dieneri, Bittner.

Monotis salinaria, which has been found in almost all sections of these beds in Spiti, occurs in a band which varies from 6 to 8 inches in width and lies at about 100 feet below the top of the series.

¹ Memoirs, G. S. I., vol. XXIII, p. 220.

From 30 to 50 feet higher up the shales contain large numbers of *Spiriferina griesbachi* and *Aulacothyris joharensis*. A very good section is seen in the valley of the Lungtsé stream (Pl. V) which joins the Spiti river between Mání and the Pin valley. The same beds are also seen about 4 miles west of Po, on the road to Dankhar, where they have been brought down by a fault, and again near Sozona E. G., on the path leading to the Mánirang Pass. This is no doubt the outcrop from which specimens of *Spiriferina griesbachi* were collected by Mr. Griesbach.¹ The only ammonite which has been obtained from these beds is *Distichites* n. sp., of which only fragments were found.

In spite of the apparent absence of *Sagenites*, this horizon was provisionally correlated with Diener's "Sagenites beds" of Painkhanda; this correlation was subsequently found by Dr. von Krafft to be correct, for, at the Bambanag cliff in Painkhanda, the "Sagenites beds" are overlain by a quartzite series identical, both lithologically and faunistically, with that which occurs immediately above the Monotis shales in Spiti.

The quartzite series forms one of the most constant and characteristic horizons of the upper trias of Spiti, and consists of white and brown quartzites, with subordinate bands of limestone. In most sections the quartzite can be seen at a distance of several miles, forming a thin, white band, which stands out among the darker brown and grey beds in the high cliffs of the upper trias. With the quartzites are intercalated limestones and bands of shale, the whole series having a thickness of about 300 feet. Fossils occur in most of the beds, and include—

Spiriferina griesbachi, Bittner.

Aulacothyris joharensis, Bittner.

¹ Pal. Indica, ser. XV, vol. III, pt. 2, p. 53.

Stoliczka's "*Spiriferina tibetica*," which he obtained from near Kibber and which he supposed to be of carboniferous age, almost certainly came from the same horizon which is exposed on the path from Kibber to the Parang Là—Stoliczka's original route. No carboniferous beds are found within many miles of Kibber, *ibid.*, p. 53.

Lima serraticosta, Bittner.

Megalodon ladakhensis, Bittner.

(?) *Dicerocardium*, sp.

Spirigera n. sp.

The quartzite series is overlain by a mass of dark grey, often dolomitic, limestone, having a thickness of about 2,300 feet. This must include representatives of the European Dachsteinkalk, lias and middle jurassic. Fossils are very rare and badly preserved, but at 50 feet above the quartzite a band of grey limestone, about 20 feet thick, contains immense numbers of *Megalodon ladakhensis*, Bittner, and *Dicerocardium himalayense*, Stol. Where the rock has been polished by the action of running water or moving ice, it has a most striking appearance, for the sections of the two bivalves, being preserved in white calcite, stand out clearly in fantastic patterns from the dark grey matrix (see Pl. XV, fig. 1). This is the characteristic horizon of Stoliczka's "Pára limestone,"¹ blocks of which are very common throughout the upper Pára valley between the Parang Là and Rupshu.

Other fossiliferous horizons.

About 200 feet higher up the massive limestone has yielded one brachiopod and two bivalves, viz.—

Spirigera noetlingi, Bittner ;

Lima cumaunica, Bittner; and

Lima serraticosta, Bittner.

In addition to these, gastropods and bivalves have been found at about 400 feet above the quartzite series, and a species of *Spiriferina* closely resembling *S. obtusa*, Oppel, about 400 feet higher still, while at about 370 feet below the top of the limestone mass, Dr. von Krafft found an ammonite very nearly allied to, if not identical with, *Stephanoceras coronatum*, Brug.; the horizon at which this fossil occurs may therefore represent the middle oolite, and since there is no trace of unconformity in this great limestone series anywhere in Spiti, the beds

¹ Memoirs, G. S. I., vol. V, p. 124.

lying between the quartzite series and the horizon of *Stephanoceras coronatum* must include the uppermost trias, rhætic and lias. In the present state of our knowledge of these beds it is impossible to attempt any more detailed subdivision.

The highest beds of the limestone, immediately underlying the Jurassic limestone. Spiti shales, represent the upper part of Stoliczka's "lower Tagling limestone," which he referred to the lias. Fossils are numerous, consisting chiefly of belemnites, bivalves and gastropods. The recent collections have not yet been worked out, but in view of the fact that the limestone underlies, with perfect conformity, the Spiti shales, which have been proved by Uhlig to be of uppermost jurassic age, there is *primâ facie* evidence for referring it to the upper jurassic and possibly upper part of the middle jurassic.

UPPER JURASSIC.

The Spiti shales are too well known to require more than passing mention; they have been fully described by Spiti shales. Stoliczka who examined them in their typical locality, in the neighbourhood of Kibber, Langja and Giumal, where they form rolling downs, capping the high limestone cliffs on the left side of the Spiti river. The specimens collected from the shales are now in the hands of Professor Uhlig by whom they are being described; a portion of his manuscript has already reached India, and from this it appears that several of the species of ammonites show a tithonian and lower neocomian facies, and the Spiti shales must therefore be regarded as uppermost jurassic, and possibly in part younger.

In addition to Stoliczka's original "jurassic ellipse,"¹ Spiti shales also occur along the higher ridges on the right side of the Spiti river and form a narrow strip running above Mání, over the saddle of the Mánirang, and on into Bashahr.

CRETACEOUS.

At Giumal, Kibber and Chikkim the Spiti shales are overlain, with interstratification, by hard, yellow and brown Giumal sandstone. sandstones and quartzites, which constitute Stoliczka's "Giumal sandstone," which was referred by him to the upper jurassic. Fossils are fairly common in the lower beds, many bivalves—usually, however, badly preserved—occurring near Giumal and Chikkim, while casts of *Stephanoceras* and *Perisphinctes* were found near Kibber and Chikkim. These sandstones are undoubtedly of cretaceous age.

The highest member of the stratigraphical series of Spiti consists of a bed of grey or whitish limestone, about 100 feet thick, overlain by soft, grey, calcareous Chikkim limestone and Chikkim shales. shales. These beds form a synclinal on the summit of Chikkim "station," behind the village of the same name, and are found also in the upper reaches of the Lingti river, above Lilang. Fossils are very rare and appear to be confined to the limestone, which has yielded one belemnite, fragments of *Rudistes* and *Foraminifera*, including the genera *Cristellaria*, *Dentalina* and *Haplophragmium*. With the exception of the belemnite, all these fossils were found also by Stoliczka, who therefore referred the limestone to the cretaceous system. The overlying shales are greatly folded and their thickness cannot be determined, but it appears to be about 150 feet: in spite of careful search, no trace of fossils has been found in them.

The first systematic account of the mesozoic rocks of Spiti was given by Stoliczka, who subdivided the whole group into the following series:—

Chikkim shales	} Cretaceous.
Chikkim limestone	
Giumal sandstone	} Jurassic.
Spiti shales	
Tagling (upper)	} Lias.
Tagling (lower)	
Pára limestone	Rhætic.
Lilang limestone	Trias.

The four highest of these represent well-defined lithological units each of which, with the exception of the Chikkim shales, has yielded fossils and can be referred with a fair degree of certainty to its European equivalent; for this reason, and also since the same terminology has been employed throughout the Himálayas, Stoliczka's nomenclature has been retained. It has, however, been found necessary to discard the names given by him to the lower members of the group.

The "Lilang limestone" included, according to Stoliczka, the whole of the trias then known in Spiti, that is to say, the beds included between the base of the muschelkalk and the base of the rhætic. It was subsequently found by Mr. Griesbach that the lower trias was well represented, while during the last few years it has been proved that much of Stoliczka's rhætic belongs in reality to the upper trias; and since most of the fossiliferous horizons of the trias of Spiti can now be referred to their European equivalents, the retention of the term "Lilang limestone" would be both superfluous and confusing.

For similar reasons the term "Pára limestone" has also been discarded, for it was supposed by Stoliczka to represent the rhætic stage, but as no horizons have yet been found in Spiti which can be definitely referred to that stage, while the "Pára limestone" includes both upper trias and lias, the term ceases to have any significance, for it represents neither a stratigraphical nor yet a lithological unit, both its upper and lower boundaries being undefined.

In the case of the "Tagling limestone," the same difficulty arises. Stoliczka includes in that series a mass of limestone, 2,000 feet thick, underlying the Spiti shales. This must, therefore, include both the middle and lower jurassic, and probably also the rhætic, should this stage be represented in Spiti. It was divided by Stoliczka into two groups, an upper and a lower, the former of which presented the curious anomaly of a formation occurring in only two localities, between the "lower Tagling limestone" and the Spiti shales, which he stated at the same time to be conformable to one another. A recent examination of the "upper Tagling limestone" in one of these localities—the Parang

Là—has proved that it is in reality a part of the “lower Tagling limestone” which has been brought into its present position by an overfold.

A great advance was made in our knowledge of the Spiti trias by the work of Mr. Griesbach, who found that not only was the lower trias well developed, but that the whole series of sedimentary beds from permian to jurassic was very similar to that of Kumaon and Garhwál, and he was then enabled to correlate the trias of those districts with that of Spiti. The surveys carried on during the last few years have tended chiefly to confirm and amplify his conclusions, especially with regard to the lower and middle trias, some small modification only being necessary in regard to the upper parts of that system.

CORRELATION OF THE MESOZOIC BEDS OF SPITI WITH THOSE OF OTHER PARTS OF THE HIMÁLAYAS.

The work of Mr. Griesbach and of Professor Diener in Garhwál and With Kumaon and Garhwál. Kumaon and of Mr. Griesbach in Spiti, renders it now a comparatively easy task to correlate, with a fair approach to accuracy, the mesozoic beds of these two areas. This had been undertaken by the late Dr. von Krafft, whose paper on the subject will form part 2 of this volume: no further details need therefore be given here.

With that part of the Himálayas which lies to the north-west of Spiti, correlation is, unfortunately, almost impossible, for, with the exception of parts of Southern Rupshu, which With Kashmir. were examined by the present writer in 1899 and 1901, the Kashmir State has not been surveyed in any detail, Mr. Lydekker's memoir on the “Geology of Kashmir,” the work of Godwin Austen, and observations by Dr. Stoliczka along the route to Yarkand, being almost the only sources of information available.

Owing to the great extent of the area surveyed by Mr. Lydekker, his work was necessarily carried out on broad lines only; he included all the mesozoic systems, with the younger palæozoic, in his “Zánskár system,” which comprised Stoliczka's Kuling series, Lilang limestone,

Pára limestone, Tagling limestone, Spiti shales, Giumal sandstone and Chikkim limestone and shales, while he employed the term "supra-Kuling series" for the whole of the triassic and jurassic systems. Hence no attempt can be made to correlate the beds of Kashmir generally with those of Spiti, until the stratigraphy of the former area has been worked out in much greater detail. At present we know merely that muschelkalk and upper triassic beds, apparently similar to those of Spiti, have been found at a few localities,—Sonamarg, Vihi, and Gurez,—and it is probable that lower trias and other subdivisions of the mesozoic group will be found to exist.¹

Of the areas to the north-west and north of Kashmir, our knowledge is equally scanty, but *Monotis salinaria* was found by Stoliczka near Aktash on the Pamir, in a rock which appears to be lithologically identical with that in which the same fossil occurs in Spiti.²

CORRELATION WITH THE TRIAS OF EUROPE.

It has been seen that the mesozoic beds of Spiti afford an unbroken series of deposits from lowermost trias to cretaceous, and since many of the characteristic species of the trias of Europe occur also in Spiti, it is possible to recognise many of the stages into which the European sequence has been divided; we thus find representatives of the muschelkalk, ladinic, carnic, and juvavic stages. In such a complete series, however, where individual sections frequently exhibit an unbroken sequence, bed upon bed, from one end of the trias to the other, without a trace of unconformity or gap of any kind, it is natural that horizons should be found which are, so far as we know, not represented in Europe: thus the small band of limestone lying upon the uppermost bed of the muschelkalk contains forms common both to

¹Since the above was written, lower triassic fossils have been found by Dr. Noetling in Kashmir.

²In this connection, it is interesting to note that this very characteristic species has recently been found by Mr. Vredenburg in an extensive system of shales and shaly limestones in the Zhob valley in Baluchistán. See General Report, G. S. I., 1901-1902, p. 31.

that stage and to the ladinic, thus constituting a passage-bed from the one to the other. More detailed work among the upper triassic rocks will also, in all probability, reveal similar gradations between the other stages. It would therefore seem unreasonable to attempt to draw imaginary lines which should represent hard-and-fast boundaries between any two stages; we can merely indicate certain beds of the Himalayan sequence which include the representatives of the smaller European subdivisions. The complete sequence of the mesozoic beds of Spiti will be found in the annexed table, in which, however, no attempt has been made to fix the limits of the corresponding stages of Europe.

		Probable European equivalents.		Thick-ness.
CRETACEOUS			"Chikkim Grey shale.	150 ft.
			"Chikkim Grey limestone.	100 ft.
			"Giumal Sandstone.	300 ft.
JURASSIC	UPPER		"Spiti shales."	500 ft.
	MIDDLE AND LOWER	Representing oolite, lias (and ? rhatic)	Limestones, chiefly unfossiliferous, but containing <i>Stephanoceras</i> cf. <i>coronatum</i> , Brug. (about 1,800 feet above base). <i>Spiriferina</i> cf. <i>obtusa</i> , Oppel (about 800 feet above base).	2,300 ft.
TRIAS	UPPER	Juvavic	<i>Megalodon lada'hensis</i> , Bittner (near base).	
			"Quartzite series." White and brown quartzites, with shales and limestones: containing <i>Aulacothyris joharensis</i> , Bitt. <i>Lima cumaunica</i> , Bitt. <i>Spiriferina griesbachi</i> , Bitt.	350 ft.
			"Monotis shales." Sandy and shaly limestones, weathering brown: with <i>Spiriferina griesbachi</i> , Bitt. <i>Aulacothyris joharensis</i> , Bitt. <i>Monotis salinaria</i> , Bronn.	300 ft.
			"Coral lime-stone" Coral limestone, with <i>Spiriferina griesbachi</i> , Bitt. <i>Rhynchonella bambanagensis</i> , Bitt.	100 ft.
			"Juvavites beds" Brown, sandy and shaly limestones, sandstones and shales, with <i>Paratibetites tornquisti</i> , Mojs. <i>Juvavites</i> aff. <i>ehrlichi</i> , v. Hauer. <i>Hauerites</i> n. sp. (near base).	500 ft.
		Carnic	"Tropites beds" Dolomitic limestone. Limestone and calcareous shale, with <i>Tropites</i> cf. <i>subbullatus</i> . " cf. <i>discobullatus</i> , Mojs. <i>Chydonautilus griesbachi</i> , Mojs.	900 ft.
			"Grey shales" Grey shales and shaly limestones, with <i>Spiriferina shalshalensis</i> , Bitt. <i>Rhynchonella lankana</i> , Bitt. (about 300 feet above base). <i>Joannites cymbiformis</i> , Wulf. <i>Trachyceras</i> cf. <i>aonoides</i> , Mojs (at base).	500 ft.
			"Halobia beds" Hard, dark limestone, with <i>Halobia</i> sp. <i>Arcestes</i> sp.	140 ft.
	MIDDLE	Ladinic	"Daonella lime-stone" Hard, dark limestone, with <i>Daonella lommeli</i> , Wissm.	145 ft.
			"Daonella shales" Thin-bedded, black limestone, shaly limestone and shale, with— <i>Daonella lommeli</i> , Wissm. " <i>indica</i> , Bittner <i>Ptychites gerardi</i> , Blanf.	160 ft.
		Muschelkalk	Upper Limestone, with shaly and concretionary bands; with <i>Ptychites rugifer</i> , Oppel, and other characteristic muschelkalk forms.	20 ft.
			Lower Grey limestone, in thin beds; with— <i>Ceratites subrobustus</i> , Mojs. <i>Sibirites prahlada</i> , Diener. <i>Spiriferina stracheyi</i> , Salter.	6 ft.
	LOWER		Nodular limestone, with few fossils, but containing lower trias ammonites in the lower beds.	60 ft.
			Shaly limestone, with <i>Rhynchonella griesbachi</i> , Bittner.	40 ft.
			Limestone, with <i>Aviculopecten luehmatis</i> , Bittner.	
			"Hedenstræmia beds" Limestone and shale, in thin beds; with <i>Hedenstræmia mojsisovicsi</i> , Diener. <i>Flemingites rohilla</i> , Diener. <i>Danubites nivalis</i> , Diener.	
			"Meekoceras zone." Limestone and shale; with <i>Meekoceras</i>	6 ft.
Age doubtful; lower trias or permian			"Ophiceras zone" Limestone with <i>Ophiceras</i>	
			"Otoceras zone" Limestone with <i>Otoceras</i>	
			Productus shales	
PERMIAN				

CHAPTER VI.

RUPSHU.

With the exception of the local peculiarities due to the unconformities between the cambrian and silurian, and carboniferous and permian systems, respectively, and which have already been noticed in the previous chapters, the characters of the stratigraphical systems of Spiti and Bashahr are so constant that detailed descriptions of a number of individual sections would be superfluous. Further to the north, however, in Rupshu, the beds have been so greatly altered both by dynamo- and contact-metamorphism, that their relations to the Spiti systems can be traced only with great difficulty.

The valley of the Spiti river is bounded on the north by a chain of snow-clad peaks and ridges, which constitute the eastern extension of the Baralachar Range.

From Spiti, three routes lead through this range to Rupshu—

(1) *viâ* the Tagling Là and upper Pára valley;

(2) *viâ* the Parang Là and upper Pára valley;

these two routes converge at about 15 miles below the Parang Là;

(3) from lower Spiti, *viâ* Kurig and Kharak in Western Tibet (To-Tzo), along the lower Pára valley, to Chumar and Lám Tso.

By taking the third route, the present writer was enabled to trace out the connection of the beds of the one area with those of the other, and it has now become possible to refer the metamorphic rocks of Rupshu to their comparatively unaltered representatives in Spiti.

The high ranges between Spiti and Rupshu are composed chiefly of rocks of mesozoic age, amongst which the upper triassic coral limestone is a most conspicuous and useful horizon. In many cases, especially in Rupshu, it has been converted by metamorphism into a white dolomite, but still retains its numerous corals. Below this

horizon, all traces of fossils have as a rule been obliterated and the greater part of Rupshu consists, as stated by Stoliczka, of metamorphic schists, to which, however, he did not attempt to assign

Effects of metamorphism.

any definite age. The same rocks were subsequently classed by Lydekker among his "metamorphic Panjals and archæan." The upper part of this series is well-exposed in the Pánpko, Pára and Chepzi valleys, where it consists of crushed limestones, slates and calc-schists. Amongst these, representatives of the middle and lower trias and permian can be traced with a great degree of certainty, and correlations based at first on lithological grounds were subsequently confirmed by the discovery of fossils, badly crushed but still recognisable; they are, however, very rare, and have been found only in two localities, in the Pánpko river, near Kiangshisa, and in the Pára river, near Sitang Gongma. At the former locality *Daonella indica* was found in black calcareous slates, which evidently represent the ladinic stage of Spiti, and in the Pára river the *Productus* shales were recognised near Sitang Gongma, where they are represented by dark slates containing the characteristic fossils. The *Productus* shales are underlain by calcareous schists and crushed limestones, which locally contain immense numbers of crinoid stems, and which presumably represent the calcareous beds which underlie the *Productus* shales in Spiti. They pass down into crushed grits and conglomerates, which clearly represent the permian conglomerates seen near Po. They are very well exposed in the Pánpko river and also in the valley of the Chepzi stream, and can be traced along the hills on either side of the Pára river near Chepzi. Below these a series of slates and metamorphic schists occupies the greater part of Rupshu between the Pánpko river and Narbo Sumdo on the one side and the range separating Rupshu from Hánle on the other. To the south of this range, near the Shálshál Pass and at Shálshál Dengo E. G., the schists are underlain by white and dark-grey crystalline limestones, with interbedded white quartzites, which most probably represent the carboniferous beds of the Lipak river.

Between Narbo Sumdo and the northern end of Tso Moriri the whole of this palæozoic series can be traced, the Representatives of palæozoic systems. calcareous schists, conglomerates and quartzites of the permian being underlain by the altered representatives of the rest of the Po series of Spiti. A little to the south of Korzok, the siliceous beds are underlain by calc-schists and crystalline limestone, as already recorded by Mr. Oldham.¹ From Korzok a small ridge runs to the northern end of the lake; this ridge consists of calc-schist and crystalline limestone with some bands of white quartzite, the whole similar, except in the somewhat smaller thickness of the quartzite, to the section seen at Shálshál Dengo. These beds have, therefore, been referred also to the carboniferous, but it is possible that they may be also partly silurian.

The limestones and quartzites are underlain by slates and schists which gradually become garnetiferous, then felspathic, and pass down into the so-called "Tso Moriri gneiss."

This rock was cursorily examined by the present writer in 1899, and on account of its apparent position among Tso Moriri gneiss. the palæozoic beds it was suggested² that it might possibly be a highly metamorphosed representative of the lower silurian quartzite of Spiti. Subsequent determination of the microscopic and chemical characters of the rock, however, showed that there was no evidence in favour of regarding it as primarily of sedimentary origin.

As already stated by Oldham (*loc. cit.*), it forms an apparently well-bedded series, with foliation parallel to bedding, the beds being about two feet thick. In mineralogical composition, it is chiefly an *augen* gneiss, with large "eyes" of feldspar. Most of the beds are composed of a quartz-feldspar-mica rock, with rods of schörl on the foliation planes. The quartz frequently occurs as a mosaic of small grains. The feldspar is chiefly orthoclase and microcline with a little plagioclase, while the mica is a pale, often colourless

¹ Records, G. S. I., vol. XXI, p. 153.

² General Report, G. S. I., 1899-1900, p. 197.

and silvery, magnesia mica. In hand specimens it resembles muscovite, but under the microscope appears to be perfectly uniaxial, while chemical analysis shows it to contain a large amount of magnesia: it must therefore be classed under biotite.

With this gneiss are associated bands of white quartz-felspar-muscovite rock, containing no biotite, but with a considerable amount of plagioclase and some schörl. Low down in the series, near Shakshang E. G., fine-grained quartz-biotite schist is found interbanded with the gneiss. It is composed of large quantities of dark brown biotite and finely granular quartz; with it occur also bands of a similar rock, but considerable quantities of zoisite and calcite are added to the other constituents; these two schists have many of the characters of altered sedimentary rocks.

Running through the above series, in bands usually parallel to, but occasionally crossing, their foliation, is another Intrusive biotite granite. quartz-felspar-biotite rock, foliated and gneissose, but containing biotite in irregular blotches and not in layers as in the "Tso Moriri gneiss." It has hitherto been included with the latter rock, but is almost certainly younger and intrusive in it. The same rock occurs again at Ooti E. G., about 40 miles further to the south-west, where it forms a broad, apparently gneissose, band in the middle of the metamorphic schists which represent the carboniferous and permian beds of Spiti. No signs of the *augen* gneiss of Tso Moriri are to be seen at Ooti. The true origin of this rock can only be ascertained by much more detailed work than has hitherto been possible, and must for the present remain doubtful, but the evidence so far obtained tends to show that it is a foliated biotite granite; whether it is identical or not with the common biotite granite of Rupshu is also uncertain, but it is much more foliated and may belong to an older series of intrusions.

Even more doubtful is the age and origin of the Tso Moriri Age and origin of Tso Moriri gneiss. gneiss; by Lydekker it was regarded as archæan, but its position, underlying rocks which are not older than silurian, and the gradual lithological passage from the

lowest undoubtedly sedimentary rocks into the gneiss, show that it must either represent an altered sedimentary series, which would then probably be the lower silurian quartzite, or be an old intrusive rock, in which case the gneissose beds between it and the sedimentaries would represent a contact zone.

The composition of a typical specimen of the *augen* gneiss is as follows:—

Si O ₂	.	.	.	.	.	.	.	.	75.09 per cent.
Al ₂ O ₃}	}	.	.	.	.	.	.	.	18.97 "
Fe ₂ O ₃		.	.	.	.	.	.	.
Ca O	.	.	.	.	.	.	.	.	.90 "
Mg O	.	.	.	.	.	.	.	.	.54 "
K ₂ O	.	.	.	.	.	.	.	.	3.8 "
Na ₂ O	.	.	.	.	.	.	.	.	2.1 "
H ₂ O	.	.	.	.	.	.	.	.	.39 "
									<hr/> 101.79
Specific gravity	.	.	.	.	.	.	.	.	<hr/>2.65

This, it will be seen, is the composition of a true granite, and it is not improbable that the so-called gneiss is in reality only the remains of an old crushed-out granite laccolite. A very similar rock is found in the Chandra valley, on the road from Spiti to Kulu; but in this case it is undoubtedly a foliated granite.

The final decision of this question must be left till opportunities arise for a detailed survey of this part of Ládákh; it is probable that an examination of the area lying to the north-west of Tso Moriri would throw some light on the relations of the *augen* gneiss to the sedimentary rocks as well as to the Rupshu granite.

Igneous rocks, both acid and basic, are common throughout Southern Rupshu; a few of these will be dealt with in the following chapter.

CHAPTER VII. IGNEOUS ROCKS.

The high ranges bordering Spiti on the south, west and east are as has already been stated, composed chiefly of granite ; basic intrusions occur among the palæozoic beds of lower Spiti and Bashahr and in the valleys of the Parahio and Pin rivers.

Granite.

The commonest form of this rock is a biotite granite, ranging from a fresh rock of medium grain to a foliated gneissose variety with large porphyritic feldspars. In the Sutlej valley, near Asrang and Jangi, numerous masses occur in the altered cambrian slates. The rock is here very pure and free from accessory minerals, consisting mainly of quartz, orthoclase and biotite, with a little muscovite and plagioclase.

Associated with the biotite granite in the Sutlej valley, in the Chandra valley, and in the ranges between Kulu and Spiti, are numerous veins of albite granite, containing large quantities of schörl, muscovite, beryl and, locally, garnet and kyanite. Both these types have been previously described by General McMahon and other observers and no further details need be given in the present memoir.

The Rupshu granite is very similar in general characters to that of the Sutlej and Chandra valleys, being a biotite granite with few accessory minerals ; it differs slightly, however, in containing—as at Dongan Le, where it is accompanied by eurite—a considerable amount of blue quartz. In spite of this difference it is almost certainly merely an offshoot of the Sutlej valley *massif*, for it can be traced up to the southern boundary of Rupshu and can be seen running through the high range which borders the eastern side of the Pará river above Ākse and Kharak in Western Tibet, and, were it possible to follow it through that country, it would probably be

found to be practically continuous with the intrusive masses found below Kurig on the lower Pará river.

In Spiti the granite is found intrusive only in the oldest palæozoic beds, but at Lio in Kanaur silurian limestones are penetrated by numerous veins which have altered the sedimentary rocks, the chief product of alteration being wollastonite, which occurs in great quantity about one mile above Lio on the right bank of the Spiti river.

In Rupshu the granite is intruded into the carboniferous and permian schists, while in Western Tibet it would appear to occur in the triassic limestones; in the latter case it was only seen from a distance, and the correctness of the observation cannot therefore be vouched for.

So far, therefore, as concerns the area dealt with in the present memoir it is only possible to assert that the age of the granite is post-carboniferous or possibly post-permian.

In this connection it is interesting to note that a pebble of biotite granite was found in the permian conglomerate on the left bank of the Spiti river below Dankhar which proves that a pre-permian granite must have existed in the area from which the materials forming these conglomerates were derived, that is to say, to the south and south-west of the Spiti valley.

Basic rocks.

Basic rocks, chiefly of doleritic type, occur at several localities in Spiti and Kanaur. They are in all cases intrusive, and no signs of contemporaneous or interbedded ashes or lavas have been found.

The localities at which intrusions have been noticed are: Depsá E. G., in the valley of the Parahio; Muth in the Pin valley; Po, Lari, and opposite Sumrá in the valley of the Spiti river; on the Shalkar (or Sumrá) Pass between Sumrá and Shalkar, and at Ná between Shalkar and Lio.

The Depsá rock was probably originally an augite-norite, but has undergone much alteration. It consists of lath-shaped plagioclase, greatly decomposed

Depsá: augite-norite.

augite, enstatite and ilmenite, all of which are accompanied by secondary decomposition products, including green hornblende and serpentine after augite, bastite after enstatite, leucoxene and some sphene after ilmenite. The rock is intrusive in the cambrian slates and quartzites.

About $\frac{3}{4}$ mile to the north-east of Po, on the road to Thábo, a

Po : dolerite. broad basic dyke cuts through the shales and quartzites of the Po series. The rock is composed of plagioclase, near labradorite, a pale green, slightly pleochroic

augite, apatite and ilmenite, with various secondary minerals, including chlorite, calcite and leucoxene. A very similar rock—which, however, contains also epidote—forms a dyke in the hills opposite Sumrá, and is seen again on the Sumrá Lá, while near Ná numerous dykes of decomposed plagioclase-hornblende rock, with much chlorite, cut through the carboniferous beds. The dykes of Po, Sumrá and Ná are probably all offshoots from one matrix and differ merely in degree of alteration.

In the Yituitse stream, between Sumrá and Lari, a dyke—in part
Actinolite schist a sheet—of actinolite-chlorite rock with decom-
near Lari. posed felspar, some ilmenite, and sphene, probably

represents a still further stage of decomposition.

The above rocks have no characters of sufficient interest to demand more detailed description ; it is quite certain, however, that they are intrusive, and not, as Stoliczka thought, contemporaneous flows interbedded with the slates and quartzites. It is necessary to emphasize this point, for the supposed existence of interbedded traps in beds regarded by Stoliczka as silurian has been employed as a means of correlating the volcanic beds of Kashmir and other areas with the palæozoic systems of Spiti.

Basic rocks of Rupshu.

The traverse of Southern Rupshu made by the present writer was too rapid to permit of any detailed examination of the countless basic intrusions found throughout that district. At present it is only possible to say that there appear to be two distinct series of basic rocks—a

garnetiferous and a non-garnetiferous ; of these the former appears to be much the older, and has been found only in the Garnetiferous basic rocks. " Tso Moriri gneiss," at numerous localities near the northern end of that lake, near Tso Kyagar, and between Shakshang and Púga. All the intrusions are similar to one another, and consist of a garnetiferous amphibolite, composed chiefly of actinolite and garnet, with muscovite, some untwinned felspar and quartz. No intrusions of this rock have been found in the schists which represent the younger palæozoics, although both they and the Rupshu granite are often penetrated by dykes of the second or non-garnetiferous class ; there is therefore no direct evidence of their age, but it seems probable that, were they post-carboniferous, they would be found intrusive in the beds of that system ; it is of course possible that a more detailed examination of this very interesting area may prove that they occur among the sedimentary beds as well as in the gneiss.

The non-garnetiferous rocks consist chiefly of forms related to the augite-norites, and resemble the basic intrusives found in Spiti. In the present state of our knowledge of the petrography of Rupshu, detailed descriptions of isolated specimens would be of no particular utility, but it is perhaps as well to record the fact that they occur as dykes among the carboniferous and permian beds and in the Rupshu granite ; they therefore constitute the youngest intrusive rocks of Southern Rupshu, and are probably related to the pyroxenites and other basic igneous rocks found further to the north, specimens of which have recently been described by General McMahon.¹

¹ Memoirs, G. S. I., vol. XXXI, pp. 303—329.

CHAPTER VIII.

ECONOMIC GEOLOGY.

Even were the Spiti valley rich in useful minerals, its inaccessibility would be a fatal bar to profitable exploitation.

Gypsum.

As it is, however, the only mineral obtainable in any quantity is gypsum which, as already noted by Mr. Mallet,¹ occurs at Huling and Changrizang in lower Spiti. It is also found in the valley of the Gyundi river in upper Spiti and between the Lipak and Yulang rivers in Kanaur. In the last-named locality it occurs in immense masses and thick beds replacing the carboniferous limestone (Pl. XVI). It is massive, very pure and soft, and could be mined with ease, but the cost of transport to the nearest market would be so high as to preclude the possibility of its competing with the gypsum of the Salt Range or of other more accessible localities. It is at present employed locally to some extent as a whitewash for the outer walls of houses, "chhortens" and "dukdens" (Buddhist shrines), but does not appear to be put to any other uses.

Its origin has been discussed by Mr. Mallet in the paper already quoted. He attributes it to the action of the sulphurous thermal springs which are found near the gypsum; the water of these, carrying sulphuric acid in solution, would act on the carbonate of lime of the limestones, thereby forming gypsum. That this explanation is the true one is proved by the fact that Mr. Mallet found the action still going on at the time of his visit, while the masses of gypsum near the Lipak and Yulang rivers are found to pass horizontally into unaltered limestone, and to contain lumps and masses of that rock, thus showing that the change has taken place *in situ*. Analyses made by the present writer of the massive gypsum failed to show the presence of anhydrite.

¹ Memoirs, G. S. I., vol. V.

Iron.

Red hæmatite is found in the high range about 3 miles south-west of Muth in the Pin valley. It forms a band about 3 feet thick among the cambrian trilobite beds, and boulders of it occur in the conglomerate which underlies the lower silurian quartzite. Its total extent is small, and, in the absence of fuel, it is of no economic value.

Galena.

Galena occurs in a small quartz vein, infiltrated along a fault plane in the upper triassic limestones in the hills between Po and Dankhar. It is found only in small, isolated cubes, which are laboriously extracted by the local *shikaris* for the manufacture of bullets.

Gold.

The only locality in which this mineral has been found in the area dealt with in the present Memoir is Chagya Sumdo, on the border between Rupshu and the Tibetan province of To-tzo. A few pits, from ten to fifteen feet in depth, are to be seen in the sub-recent gravels on the left bank of the Pára river. They were said to have been dug some fifteen or sixteen years previously by the Tibetans, who obtained a small quantity of gold, but eventually deserted them as not being sufficiently productive. A small amount of material was panned here, and at other localities in Rupshu, by the present writer, but no trace of gold was found.

Amethyst.

Amethyst (amethystine quartz) is common in the Suttlej valley in Bashahr, and is known to occur at several localities. Both it and the blue kyanite, which is so plentiful in Kanaur and Bhabeh, and indeed throughout Bashahr State, have been repeatedly mistaken by natives and inexperienced Europeans for sapphire.

CHAPTER IX.

CORRELATION WITH THE SIMLA SERIES.

The correlation of the metamorphosed sedimentary beds of the lower Himálayas with beds of known age in the higher parts of that range has ever been one of the most difficult problems with which the Himalayan geologist is called upon to deal. The apparent absence of fossils in the pre-tertiary rocks of the lower ranges and the discontinuity in the beds caused by the numerous intrusions of great masses of granite, leave us dependent entirely on lithological characters as a means of correlating the rocks of different areas, and in the face of such extreme variations in character of the palæozoic systems as are displayed in the sections of comparatively adjacent areas, such as Spiti and Kanaur, this method of correlation can be employed only with the greatest discretion.

In the present chapter it is proposed to deal with those aspects of the question on which the recent survey of Spiti may have thrown a little more light, that is to say, the correlation of the various beds found at Simla, and in the Sutlej valley with their possible representatives among the higher ranges to the north.

It is only within comparatively recent years that the real difficulties of this problem seem to have been realised, the earliest observers having been content to apportion, somewhat dogmatically, the various Simla beds among the fossiliferous rocks of Spiti. Subsequently, however, the question was studied more deeply by General McMahon and Mr. Oldham, who made detailed surveys of Simla and neighbouring areas and also visited both Spiti and Kashmir. The observations are embodied in numerous papers published in the "Records" of this Department, and a summary of Mr. Oldham's conclusions will be found in the "Manual of the Geology of India."¹ Of the area in which these rocks and their representatives have been studied by Mr. Oldham, only two small portions have been visited by the present

¹ Manual, 2nd Edn., pp. 132—133.

writer, *viz.*, Spiti, and the immediate neighbourhood of Simla, and any observations which may appear to run counter to the generally accepted views are put forward with diffidence and chiefly with a view to drawing the attention of future workers to certain points which appear to have hitherto escaped notice and which may help eventually to elucidate this difficult problem.

The earliest attempt at correlation was made by Stoliczka, who identified the *infra*-Blaini beds (Simla slates) with the upper part of his Bhabeh series, *i.e.*, with the beds regarded in this Memoir as of middle and upper cambrian age.

The Blaini boulder slate he correlated with the lower part of his Muth series, the Blaini limestone with the "arenaceous limestone" of the same series, and the Boileauganj quartzite and schists with his "Kuling series"; while the Muth quartzite he believed to be represented by "a small thickness of a whitish quartzose schist" above the Blaini limestone.

Adopting Mr. Oldham's classification of the Simla beds as published in Records, vol. XX, we obtain the correlation shown in the following table :—

SIMLA (OLDHAM).	SPITI (STOLICZKA).
Jutogh carbonaceous slates and limestone.	
Boileauganj quartzites and schists.	Kuling series (permian and carboniferous of present memoir).
Lower carbonaceous slates.	----- Muth quartzite (= ? devonian).
Blaini limestone.	Arenaceous limestone (= partly upper, partly lower silurian).
Upper boulder bed.	Lowest beds of Muth series (= lower silurian).
Bleach slates.	
Lower boulder bed.	
<i>Infra</i> -Blaini beds.	Upper Bhabeh series (= upper and middle cambrian).

This correlation was subsequently followed by Lydekker, who states that "there is no room for doubt as to the identity of the Panjál rocks with the Blaini and *infra*-Blaini series of [Simla] and the Muth and Bhabeh series of [Spiti]"¹: he was thus led to attribute to his Panjál system an age very much greater than now appears probable.

So far as the area touched on in the present memoir is concerned, there is a very considerable superficial resemblance between the lower palæozoic rocks of Spiti and some of the Simla beds, certain units in the one finding their exact *lithological* counterparts in the other. Thus the quartzites, slates and grits of the *infra*-Blaini beds, as seen near the tunnel on the Simla-Mashobra road, are indistinguishable in hand specimens from the cambrian rocks of the Thanam valley in Bashahr and of the Parahio valley in Spiti. Higher in the cambrian system, both in Bashahr and Spiti, are soft, intensely black carbonaceous shales, which are the exact counterpart of the carbonaceous shales of Simla, while the reddish-brown and pink dolomite of the upper cambrian of the Parahio valley bears a strong lithological resemblance to the Blaini dolomite.

In the case of the lower silurian conglomerate, the resemblance is less striking. With regard to its correlation by Stoliczka with the Blaini boulder bed, Mr. Oldham has remarked: "The Muth series of Stoliczka resembles nothing I am acquainted with in the Simla area. One thing I feel certain of, that it does not represent the Blaini group of Simla. The conglomerates of Muth are perfectly ordinary conglomerates and quite different to the very peculiar Blaini rock." So far as the conglomerate is concerned, the outcrops near Muth undoubtedly bear out Mr. Oldham's view as to its origin. In many places, however, where the rock has undergone a certain amount of shearing, the matrix resembles a fine-grained slate, though it is not in reality so fine as that of the Blaini rock, and more nearly resembles that of the Po conglomerate (see below, p. 109; see also Pl. XVII). Certainly there is no reason to look upon it as of glacial origin. At the same

¹ Memoirs, G. S. I., vol. XXII, p. 249.

time, the series frequently bears a distinct superficial resemblance to the Blaini boulder-beds; in each area there are usually two boulder-beds, separated from one another by a band of slate, while near Shián in the Pin valley the lower bed is underlain by a narrow band of rock consisting of small pebbles and angular fragments of white quartz in a dark, slaty matrix, and strongly resembling a similar narrow band of conglomerate which is found at Simla at the base of the boulder-beds, and has been traced from the Elysium spur round the flank of Jakko to the Sanjauli bazar.

So much for mere lithological resemblance: when, however, we turn to the actual sequence, we find that there is considerable discordance between the two areas. This will be readily seen by a glance at the following parallel arrangement of the beds:—

SIMLA.	SPITI.
Carbonaceous slate.	Conglomerate.
Dolomite.	Slate.
Boulder slate.	Conglomerate.
Bleach slate.	Dolomite and slate.
Boulder slate.	Carbonaceous slate.
<i>Infra</i> -Blaini slates, grits and quartzites.	Cambrian slate, grits and quartzites.

It will thus be seen that the order of the beds above the lithologically similar slates, grits and quartzites is in the one area exactly the reverse of that in the other. This cannot be explained in the present case by subsequent inversion of the strata in the Simla area: it is, however, possible to conceive of conditions under which deposition might take place simultaneously in some such reverse order in two areas not far removed from one another, but between the two, there would necessarily be found a gradation from the one series into the other. The beds between Spiti and Simla are so highly altered by dynamo- and contact-metamorphism that there is little hope of finding confirmation, or the reverse, and in view of the discrepancies between the two series, no attempt at correlation, on the strength of lithological resemblance of isolated members, could be justified. It has, however, been deemed advisable to draw attention to such points of similarity as exist.

With regard to the upper beds of the Simla series, *viz.*, the Boileauganj quartzite and the Jutogh limestone, there are so many similar combinations in Spiti—*e.g.*, lower silurian quartzite and silurian limestone, Muth quartzite and (?) devonian limestone, carboniferous quartzite of the Lipak river and carboniferous limestone—that any attempt at correlation is impossible.

Another suggested correlation, which, if subsequently found to be correct, would to some extent favour Stoliczka's original view, has been quite recently put forward by General McMahon, whose extensive acquaintance with the Blaini and *infra*-Blaini beds of the Himálayas entitles his opinion to no small weight. The correlation in question is that of a certain conglomerate, found by Major McMahon in Chitral, with the Blaini boulder-slate; a full description of the rock will be found in a recent number of the Geological Magazine¹: unfortunately, General McMahon's observations were made only on hand specimens, which are so frequently misleading.

The conglomerate is said to occur below a bed of red sandstone which is in turn overlain by limestone containing devonian fossils.² It has already been stated,³ that the sequence as recorded above distinctly recalls the conglomerate, red quartzite and limestone, *i.e.*, the silurian system, of Spiti, but in the absence of any details as to the thickness or subdivisions of the members of the Chitral beds, it is impossible to say how far the one series may represent the other, but even should the Chitral series and silurian of Spiti eventually be proved, on palæontological grounds, to be one and the same, the probability of being able to connect two such widely separated areas as Chitral and Simla seems very remote.

It is, however, interesting to note that in Hazara a somewhat similar series was found by Mr. Middlemiss who described⁴ in some detail an "*infra-trias*" conglomerate which he has correlated with the Talchir

¹ Geol. Magazine, vol. IX, No. 1, January 1902, pp. 1-8.

² *Ibid.*, No. 2, February, 1902, pp. 49-58.

³ *Supra*, p. 31.

⁴ Memoirs, G. S. I., vol. XXVI, pp. 17-23.

boulder-bed of the Salt Range, the Blaini boulder-slate of Simla and the Panjál conglomerate of Kashmir, thus referring all four to the same horizon. Of these, Mr. Middlemiss has had the opportunity of examining all but the Panjál conglomerate, and his conclusions are therefore entitled to no small degree of consideration. On the other hand, it is difficult to resist the temptation to correlate the Hazara rock with the lower silurian conglomerate of Spiti, for each of these passes up into a comparatively thin band of shale, overlain by a red—at times purple—quartzite in the one case, and by a purple sandstone in the other.

The most recent and generally accepted views with regard to the correlation of the Spiti and Simla rocks are to be found in the "Manual of the Geology of India,"¹ in which the Blaini boulder-slate is indicated as the probable equivalent of the Panjál conglomerates of Kashmir and the Talchir boulder-bed of the Salt Range, and these again referred to the permian conglomerates of Po in Spiti. The first observer to draw attention to the Po rock was General McMahon, who described an outcrop of conglomerate, seen on the road between that village and Dankhar, as consisting of large boulders in a fine-grained, slaty matrix, the whole resembling the Blaini "conglomerate."² In a subsequent paper,³ however, he appears to accept Stoliczka's correlation of the Blaini rock with the silurian conglomerate of Muth, thus following him in supposing that the cambrian and silurian rocks near that village were merely a different facies of the slates and quartzites of lower Spiti: there is now no doubt that the latter series represents the permian and part of the carboniferous systems, and this still further emphasises the futility of any attempt at correlation on the strength of mere lithological resemblance.

As has already been stated above (p. 52), the permian conglomerate of Spiti is also exposed at the junction of the Lingti and Spiti rivers below Dankhar. This outcrop was noticed both by General McMahon

¹ Manual, G. S. I., 2nd Ed., pp. 132—138.

² Records, G. S. I., vol. XII, p. 63.

³ Records, G. S. I., vol. XIV, p. 309.

and Mr. Oldham, the latter of whom draws attention to the resemblance borne by the rock to the Blaini conglomeratic slate.¹

During the recent survey of Spiti the present writer paid a considerable amount of attention to the question of the supposed resemblance of these permian conglomerates to the Blaini boulder-slates, and a detailed examination of the sections near Po and Pomarang, and also of the outcrops mentioned by McMahon and Oldham, has led him to the conclusion that the resemblance is only superficial. The Blaini boulder-slate is now generally regarded as of glacial origin, owing to the fact of its being composed of comparatively large boulders in a fine-grained, silty matrix, and the same characters have been claimed for the conglomerate seen near Po and Dankhar. This latter rock occurs among a series of typical shallow-water deposits, consisting of quartzites, grits, gritty slates, conglomerates and occasional beds of fine-grained slate. The matrix of the conglomerate varies from a coarse grit to a gritty slate, corresponding in composition to a fine-grained, somewhat argillaceous sandstone: the rock has usually undergone a considerable amount of crushing and shearing, thus being converted into a boulder-bearing slate, the included fragments varying in size from small pebbles to boulders nearly a foot in diameter; the latter, however, are rare, the pebbles being as a rule about the size of the fist.

Under the microscope, the rock appears to be an ordinary conglomerate; figs. 1 and 2 on Plate XVII represent sections of the matrix collected from the localities mentioned by Mr. Oldham and General McMahon. It will be seen that the specimen from Po is quite coarse and gritty, while that from below Dankhar is finer, but still only a gritty, arenaceous slate; this represents the finest-grained matrix that the present writer has been able to find among the conglomerates of Spiti. In addition to the conglomerate, beds of fine-grained slate, presumably representing true silts, are not uncommon in the series, but have never been found to contain pebbles or boulders, though

¹ Records, G. S. I., vol. XXI, p. 151.

frequently full of large concretions, and no pebble or boulder-bearing bed has been found with a silty matrix. There is therefore no evidence in support of the theory of a glacial origin for the conglomerates, which, with the slates, grits and quartzites with which they are associated, are just such rocks as might be expected to occur among a series of shallow-water deposits laid down in estuaries or in the neighbourhood of a shore-line.

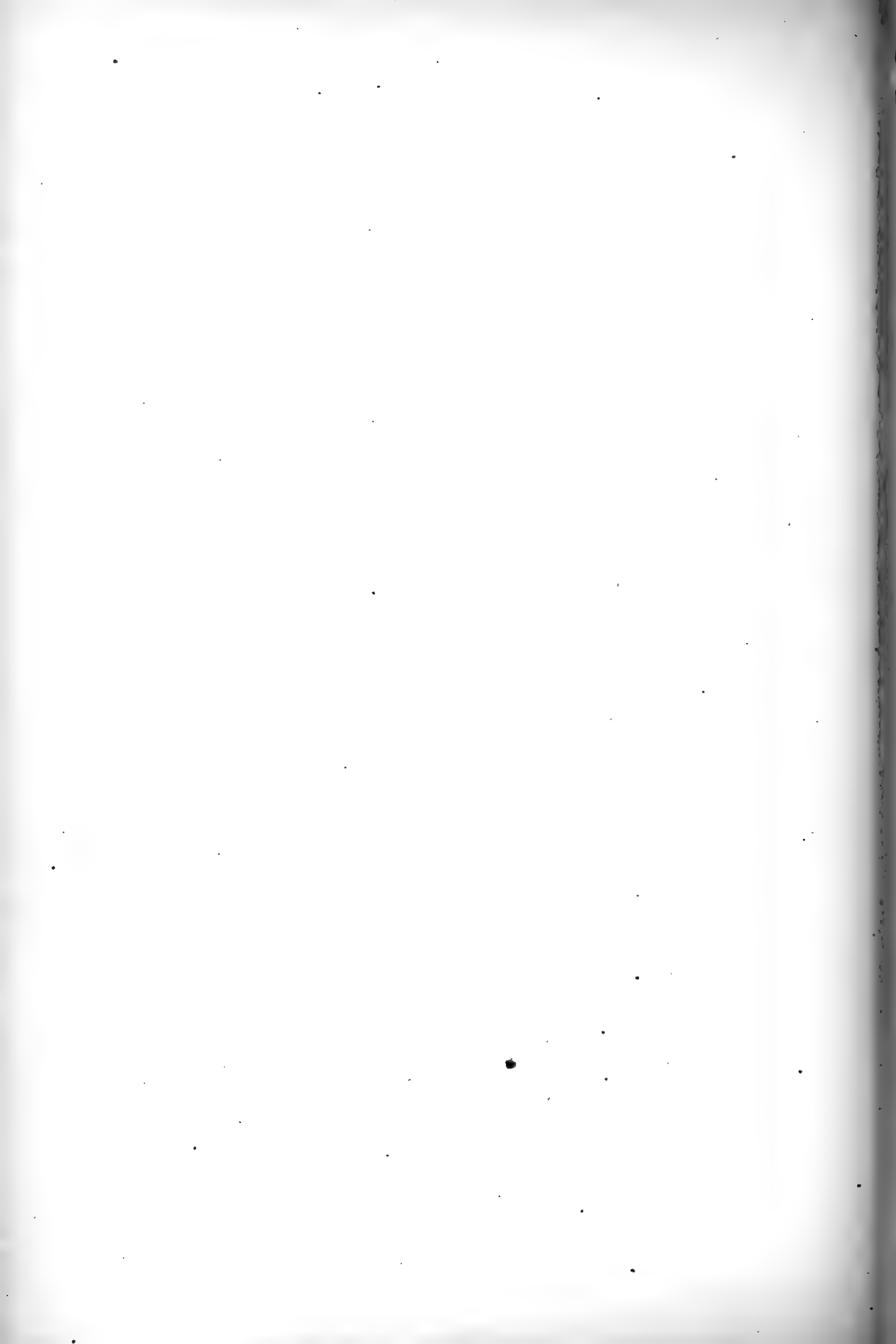
Figure 3, Plate XVII, represents the matrix of the Blaini boulder-slate as seen on the Mall at Simla, near Sanjauli bazar. It will be seen that it is very much finer than the matrix of the Spiti conglomerate, while the present writer has found that larger boulders occur in the Simla rock than are to be seen in its supposed representatives in Spiti.

It would seem, therefore, that correlation of the two series on the ground of a common glacial origin is not warranted, but this cannot be regarded as sufficient reason for denying that such correlation may still be correct.

Certain other points of resemblance were found by Mr. Oldham between the Blaini rocks and the permian beds of Spiti; one of these was the occurrence of carbonaceous shales above the boulder-bearing beds in both areas. The carbonaceous shales of Simla require little description: they are soft, densely black and graphitic, their appearance having frequently led to their being mistaken, by those not versed in such matters, for coal. On the other hand, their supposed representatives in Spiti, which have been described in this memoir as the "Productus shales," though certainly black at times, are more usually dark-brown, gritty and micaceous, with a few indistinct plant impressions in the lower beds. They have not, however, even where greatly metamorphosed, as in Rupshu, that intensely black, coaly and graphitic appearance so characteristic of the Simla carbonaceous shales, which are much more nearly related, lithologically, to the cambrian carbonaceous shales of Bashahr.

A further argument adduced by Mr. Oldham in favour of his correlation was the common resemblance of the Po conglomerate and the Blaini boulder-slate to the Panjál conglomerates of Kashmir and

to the Talchir boulder-bed of the Salt Range. The present writer has not had the opportunity of seeing either of the two last-named formations, but the recent survey of Spiti may nevertheless throw some light on the question, for it is hoped that a detailed examination of the fossils collected from the Po series may definitely fix the age of the conglomerates; at present it is only possible to say that they are either upper carboniferous or permian, but their exact horizon is still a matter of doubt. Quite recently a series of slates and limestones have been found by Dr. Noetling in Kashmir; they are said to overlie tuffs, which are not improbably the representatives of Lydekker's "Panjál system," and are said to contain permian fishes and lower Gondwana plants, in which case the underlying beds would appear to be referable to the beds at the base of the Gondwanas, or, in other words, to the Talchir boulder-bed, and should the tuff series be found to contain the Panjál conglomerate, correlation with the Salt Range might safely be considered as established. As stated above (p. 57), it is highly probable that the Po series of shales and quartzites, as well as the overlying permian beds, will be found to be continuous, from upper Spiti, at least into the Lingti valley in Kashmir, and a survey of the intervening area should, therefore, definitely determine the relation between Lydekker's "Panjál system" and the neighbouring beds of Spiti; and such a correlation, once established, would probably link up the Salt Range with both Spiti and Kashmir. This, however, would not necessarily bring us much nearer to the solution of the problem of the age of the Blaini rocks, for we have seen that there are two series in Spiti, differing widely from one another in age, each of which has certain points of lithological resemblance to the Simla beds, but in neither case do there appear to be sufficient grounds for definite correlation, and until evidence of a more satisfactory nature can be obtained, we must look upon the question as still unsolved.



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APPENDIX.

Bibliography.

An extensive bibliography of Himalayan literature published before the year 1891, has been given by Mr. Griesbach in his memoir on the Geology of the Central Himálayas (Memoirs of the Geological Survey of India, XXIII, pages 3—9), and a further list of works dealing with the North-West Himálayas and neighbouring areas will be found in Mr. Lydekker's "Geology of Kashmir" (Memoirs of the Geological Survey of India, XXII). Since the appearance of those Memoirs, a considerable amount of literature has been published on the subject of the palæontology and stratigraphical geology of the Himálayas, and since this has a more or less direct bearing on the subject of the present memoir, it has been included in the following list of papers relating to Spiti and adjacent areas:—

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LIST OF PLATES.

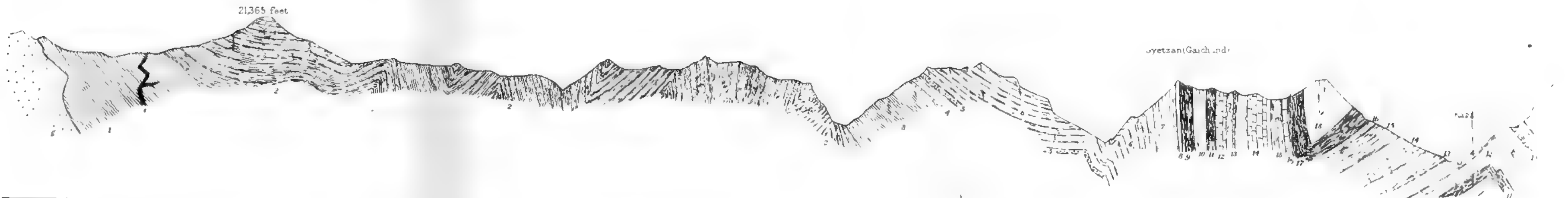
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|--------|---|
| PLATE | I. fig. 1. Profile of hills on left side of Rátang river. |
| | fig. 2. Section from head of Parahio river to Kágá. |
| ,, | II. Profile of carboniferous beds below Tangá, on left side of Lipak river. |
| ,, | III. fig. 1. Section along right side of upper Gyundi river. |
| | fig. 2. Section of upper jurassic beds behind Máni. |
| | fig. 3. Section from Lari to peak above Sopona. |
| ,, | IV. Middle and lower trias in hills south-east of Muth. |
| ,, | V. Section through the upper trias between the Spiti river and Ensa. |
| ,, | VI. Unconformity in upper cambrian beds on right bank of Parahio river. |
| ,, | VII. Junction of cambrian and silurian beds on left side of Parahio river. |
| ,, | VIII. Hills behind Muth, seen from near Shián. |
| ,, | IX. Palæozoic beds in range between Parahio river and Muth. |
| ,, | X. Muth quartzite on ridge between Tėti and Thanam valleys. |
| ,, | XI. Unconformity below Productus shales, showing manner in which the Muth quartzite dies out : left side of upper Thanam river. |
| ,, | XII. Permian and triassic beds between Po and Thábo. |
| ,, | XIII. Upper triassic beds on north side of Manirang. |
| ,, | XIV. Upper trias, in cliffs above Spiti river between Chikkim and Hansi. |
| ,, | XV. fig. 1. <i>Megalodon</i> limestone. |
| | fig. 2. Granite veins in cambrian slates above Náku. |
| ,, | XVI. Masses of gypsum among carboniferous limestones, between Lipak and Yulang rivers. |
| ,, | XVII. fig. 1. Matrix of permian conglomerate ; specimen from Po. |
| | fig. 2. do. do. ; below Dankhar. |
| | fig. 3. Matrix of Simla boulder-slate. |
| XVIII. | Geological Map. |



- 6. Red (lower silurian) quartzite.
- 7. Silurian limestone.
- 8. Muth quartzite.
- 9. Productus shales.
- 10. Lower trias and muschelkalk.
- 11. Daonella shales.

PROFILE OF HILLS ON LEFT SIDE OF RATANG RIVER.

- 12. Daonella limestone.
- 13. Grey beds.
- 14. Dolomite, with Tropites beds.
- 15. Juvavites beds.
- 16. Coral limestone.
- 17. Monotis shales.



- 1. Granite.
- 2. Epulorite.
- 3. Cambrian slates and quartzites, altered by contact with igneous rocks.
- 4. Cambrian slates.
- 5. Cambrian trilobite beds.

- 6. Cambrian Dolomite.
- 7. Lower silurian conglomerate.
- 8. Red (lower silurian) quartzite.
- 9. Silurian limestone.
- 10. Muth quartzite.

SECTION ALONG THE PARAHIO RIVER, SPITI.

- 11. Productus shales.
- 12. Lower trias and muschelkalk.
- 13. Daonella shales.
- 14. Daonella limestone.
- 15. Grey shales.

- 16. Dolomite, with Tropites beds.
- 17. Juvavites beds.
- 18. Coral limestone.
- 19. Monotis shales.
- 20. Quartzite series.

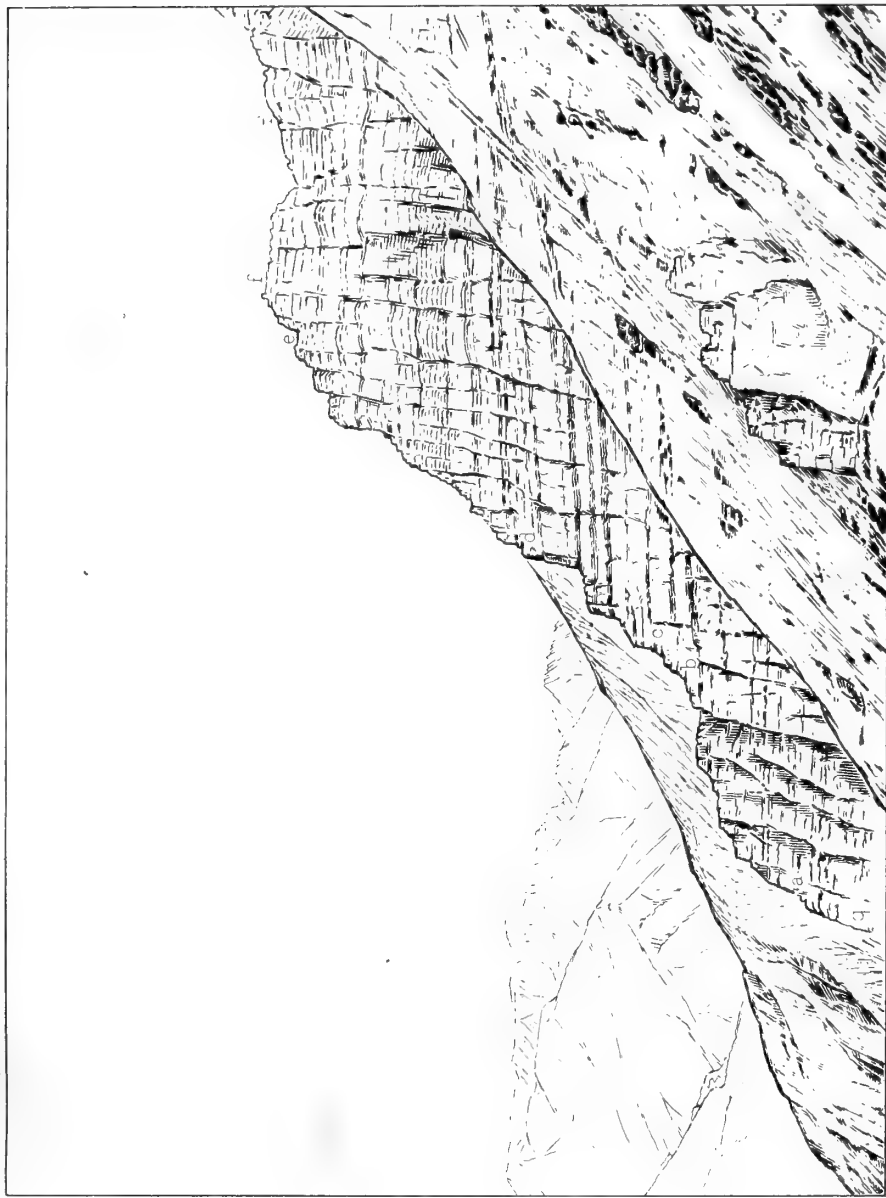
PLATE 2.

- a* to *f*. Fossiliferous shales and limestones. (See pages 37 to 41.)
g. Unfossiliferous white quartzite.

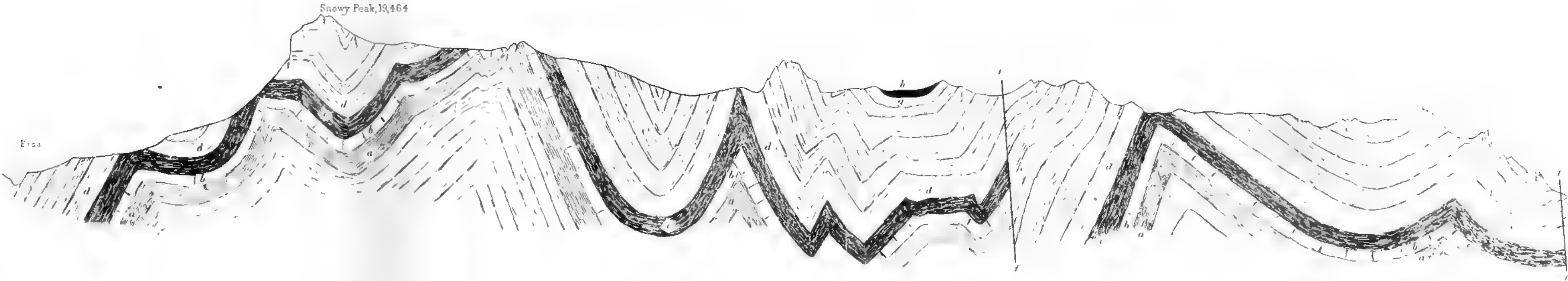
GEOLOGICAL SURVEY OF INDIA

H. H. Hayden.

Memoirs, Vol. XXVI. Pt. 1 Pl. 2



CARBONIFEROUS BEDS ON LEFT SIDE OF LIPAK R., BELOW TANGA E. G.

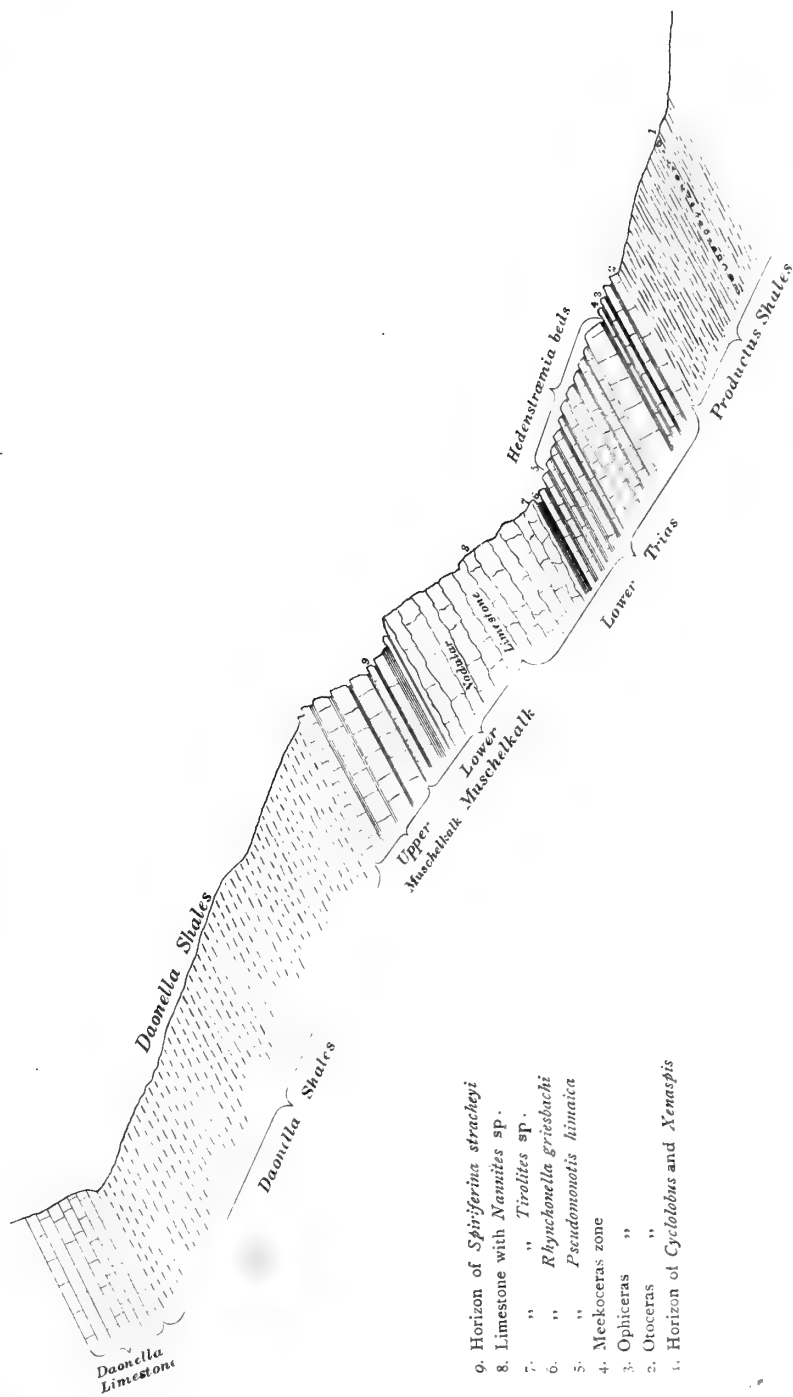


a. Juvavites beds.
b. Coral limestone.
c. Monotis shales.
d. Quartzite series.

SECTION FROM SPITI RIVER, ABOVE MANI, TO ENSA.

g. Jurassic limestone.
h. Spiti shales.
l. Daonella shales.

H. H. Hayden.



Lower and Middle Trias in hills S. E. of Muth.



From a Photograph by H. H. Hayden.

UNCONFORMITY IN UPPER CAMBRIAN BEDS, RIGHT SIDE OF PARAHIO RIVER

PLATE 7

4. Lower silurian conglomerate (No. 19, p. 14).
3. Upper cambrian shale and quartzite (No. 18, p. 14).
2. " " upper dolomite (No. 17, p. 14).
1. " " lower " (No. 15, p. 14).



H. H. Hayden, Photo.

JUNCTION OF CAMBRIAN AND SILURIAN BEDS IN HILLS
ON LEFT SIDE OF PARAHIO RIVER.

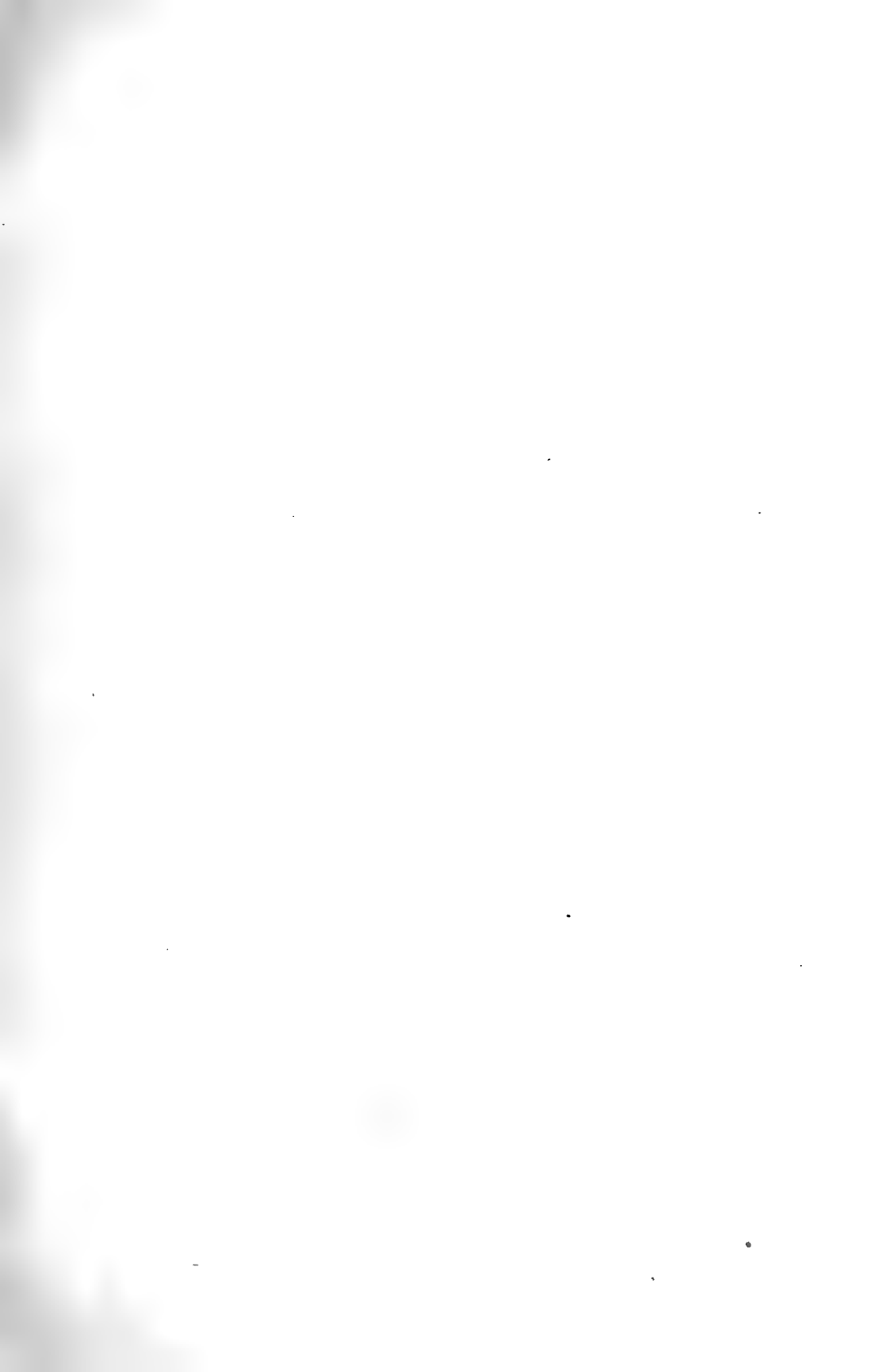


PLATE 8.

10. Tropites beds.
 9. Grey beds.
 8. Daonella limestone.
 7. Daonella shale.
 6. Muschelkalk and lower trias.
 5. Productus shales.
 4. Muth quartzite.
 3. Silurian limestone.
 2. Red lower silurian quartzite.
 - c. Lower silurian conglomerate.
 1. Cambrian slates and quartzite.
1. and c are separated from one another by a fault (see p 21).



H. H. Hayden, Photo.

PALÆOZOIC AND MESOZOIC BEDS BEHIND MUTH.
SEEN FROM NEAR SHIÁN.

PLATE 9.

7. Productus shales.
6. Muth quartzite.
5. Silurian limestone.
4. Lower silurian quartzite.
3. " " conglomerate.
2. Cambrian dolomite.
1. " slates and quartzites.



H. H. Hayden, P. 9.

PALÆOZOIC BEDS IN HILLS BETWEEN PARAHIO
AND PIN RIVERS.



PLATE 10.

6. *Daonella* shales.
5. Muschelkalk.
4. Lower trias.
3. *Productus* shales.
2. Muth quartzite.
1. Silurian limestone.

GEOLOGICAL SURVEY OF INDIA.

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt. I, Pl. I.



MUTH QUARTZITE AT HEAD OF TETI RIVER, BASHAHR.



PLATE II.

8. *Daonella* limestone.
7. *Daonella* shales.
6. Muschelkalk.
5. Lower trias.
4. *Productus* shales.
3. Muth quartzite.
2. Silurian limestone.
1. Lower silurian quartzite.

In the higher ridges the Muth quartzite had been completely removed before the deposition of the *Productus* shales.

GEOLOGICAL SURVEY OF INDIA.

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt. 4, Pl. 11.



H. H. Hayden, Photo.

JUNCTION OF PALÆOZOIC AND MESOZOIC BEDS.
UPPER THANAM VALLEY, BASHAHR.

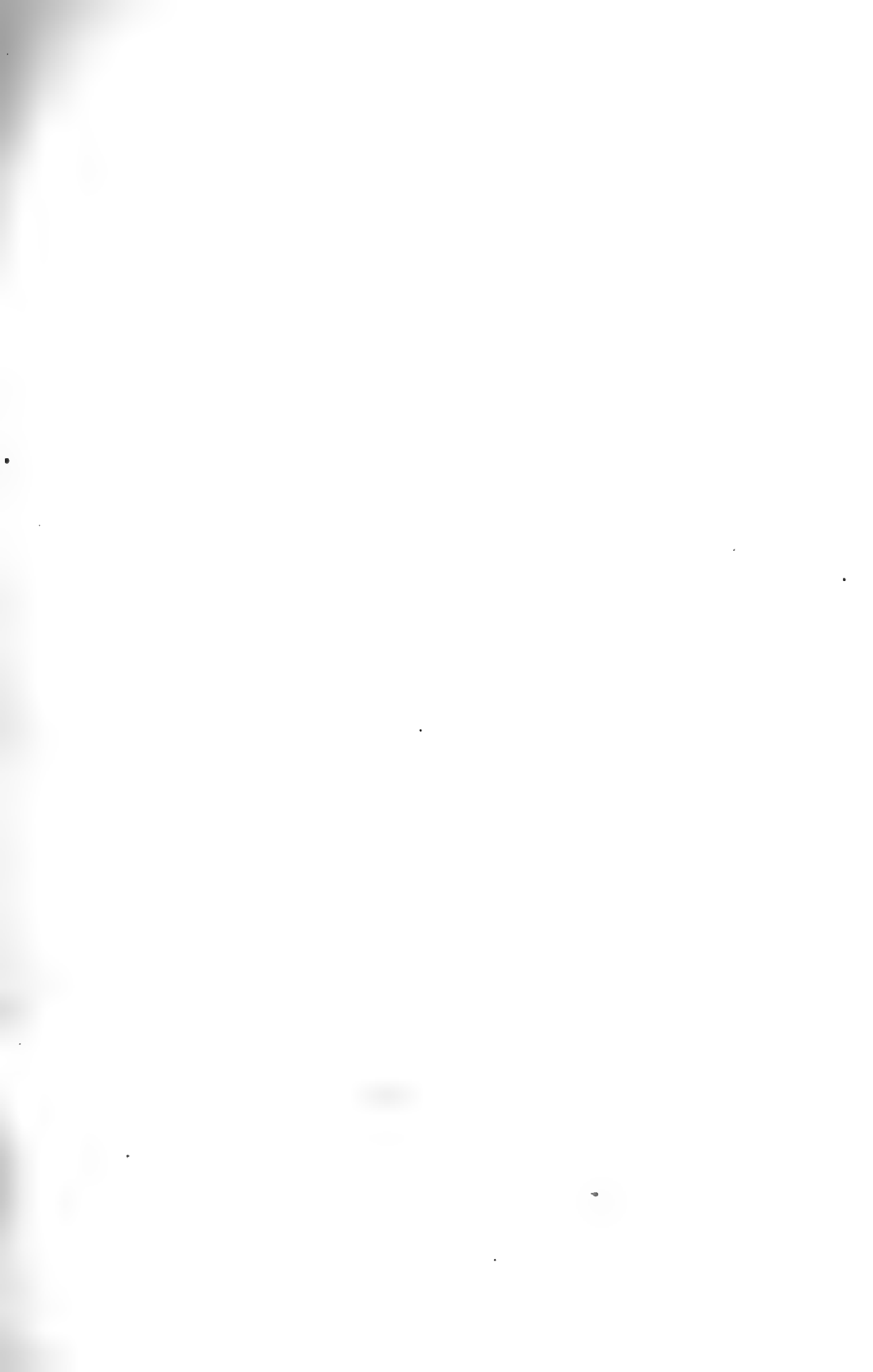


PLATE 12.

- 8 Grey beds.
7. Daonella limestone.
6. Daonella shales.
5. Muschelkalk.
4. Productus shales.
3. Lower permian conglomerate.
2. Upper carboniferous quartzite and shale.
1. Fenestella shales.

H. H. Hayden.



H. H. Hayden, Photo

CARBONIFEROUS AND TRIAS ON LEFT SIDE OF SPITI RIVER.
BETWEEN PO AND THABO.

PLATE 13

3. *Monotis* beds.
2. Coral limestone.
1. *Juvavites* beds.

GEOLOGICAL SURVEY OF INDIA.

H. H. Hayden.

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H. H. Hayden, Photo.

FOLDED UPPER TRIAS, NORTH SIDE OF MÁNIRANG PASS.

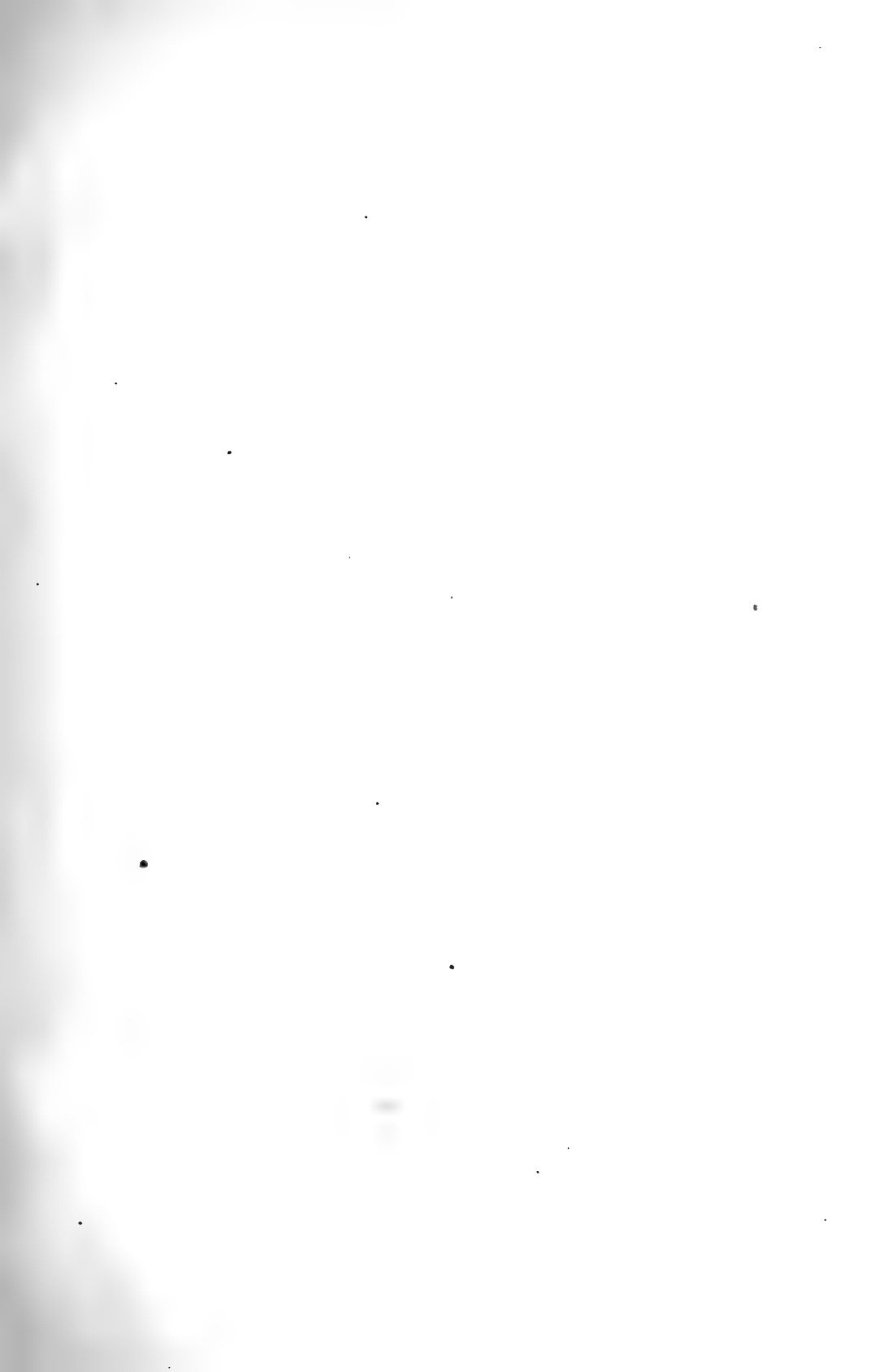


PLATE 14.

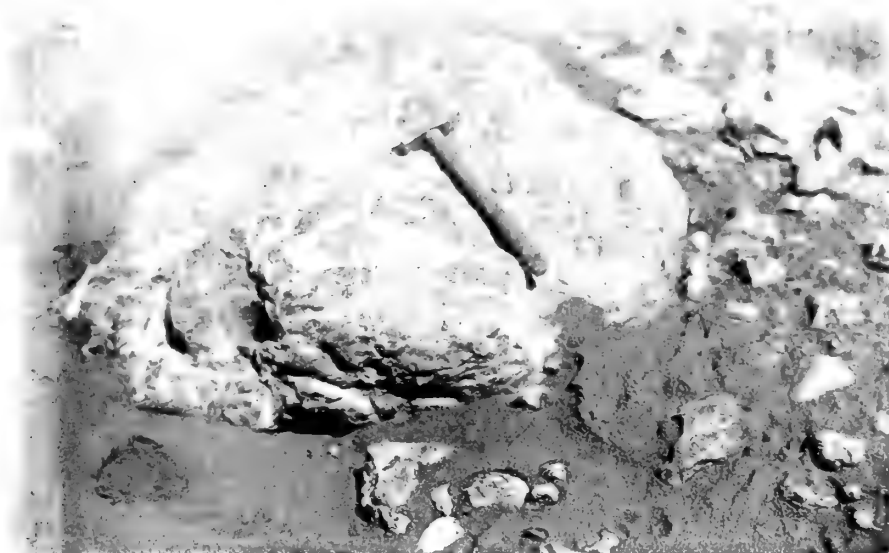
T. Upper Trias.

H. H. Hayden.



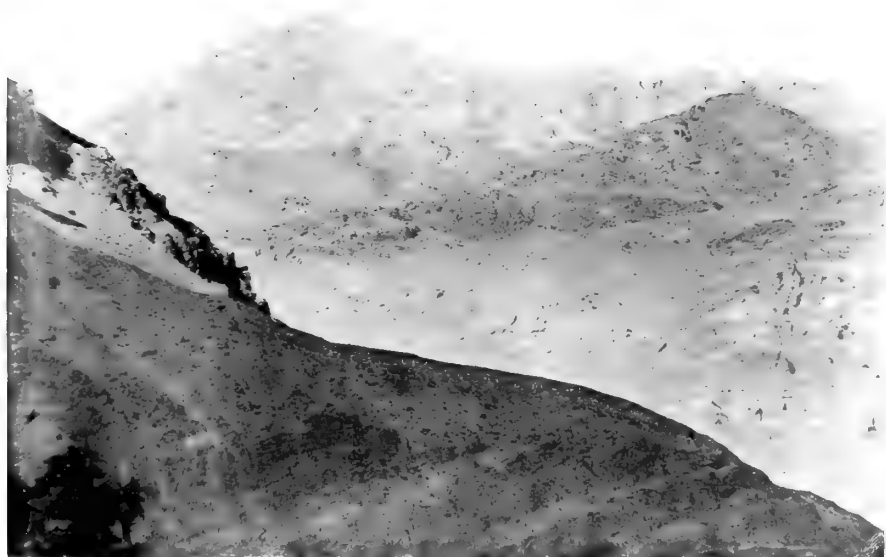
A. von Kniff, Photo.

UPPER SPITI RIVER, BETWEEN KI AND KIOTO.



H. H. Hayden, Photo.

FIG. 1. MEGALODON LIMESTONE.



H. H. Hayden, Telephoto.

FIG. 2. GRANITE VEINS IN CAMBRIAN SLATES,
ABOVE NAKU, KANAUR.

H. H. Hayden.



H. H. Hayden, Phot.

MASSSES OF GYPSUM IN CARBONIFEROUS LIMESTONES. UPPER
YULANG RIVER, KANAUR.

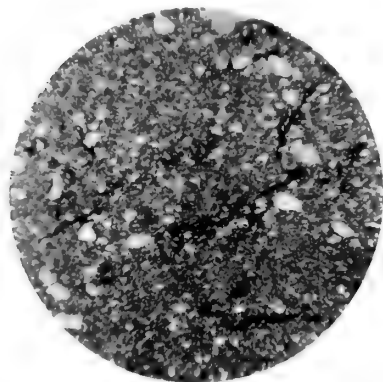


FIG. 1. MATRIX OF PERMIAN CONGLOMERATE, NEAR PO.

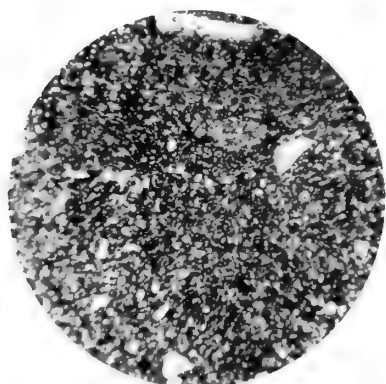
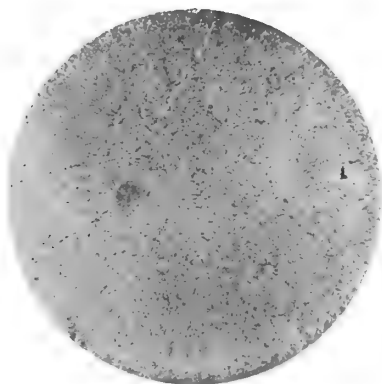
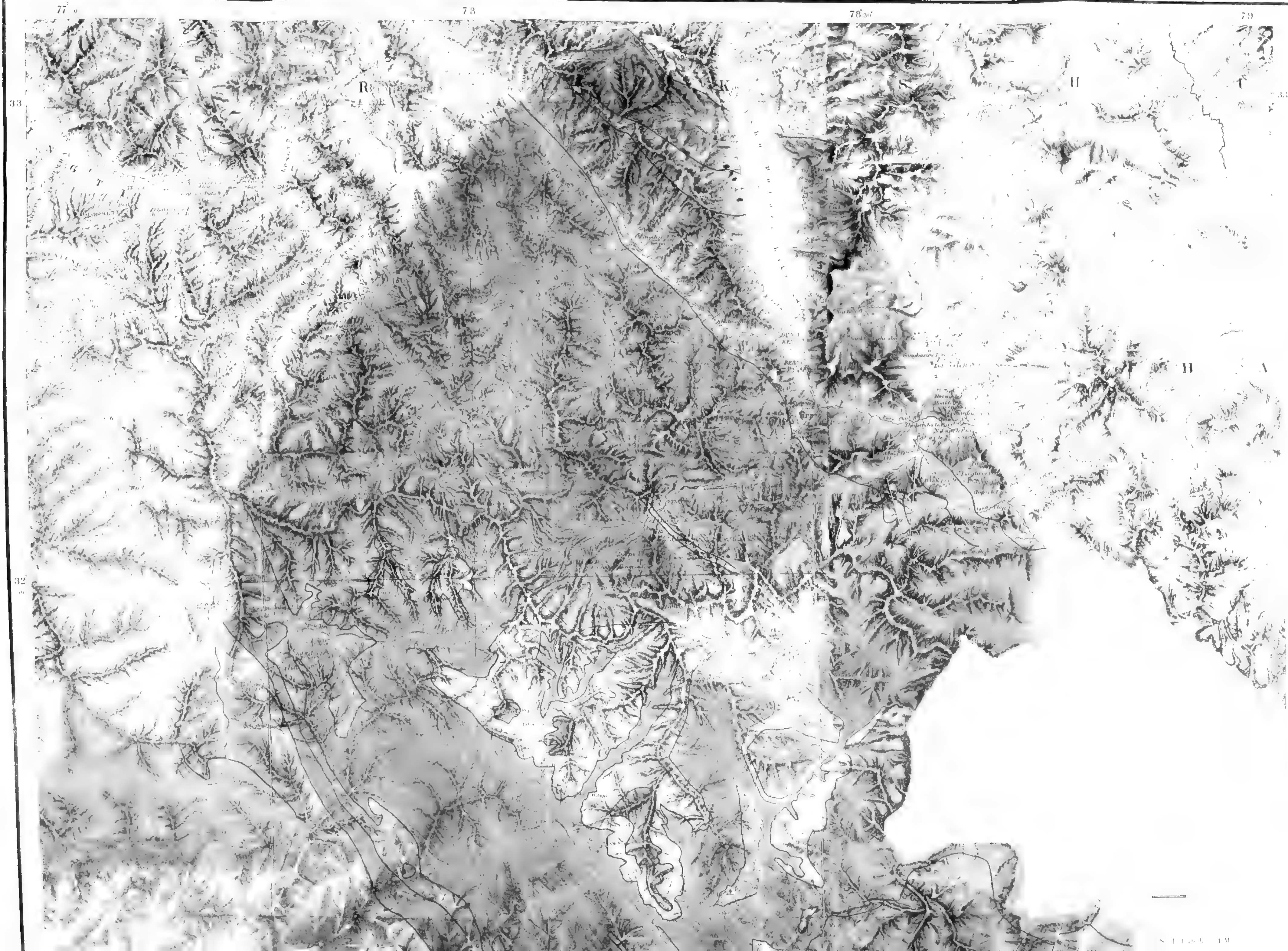


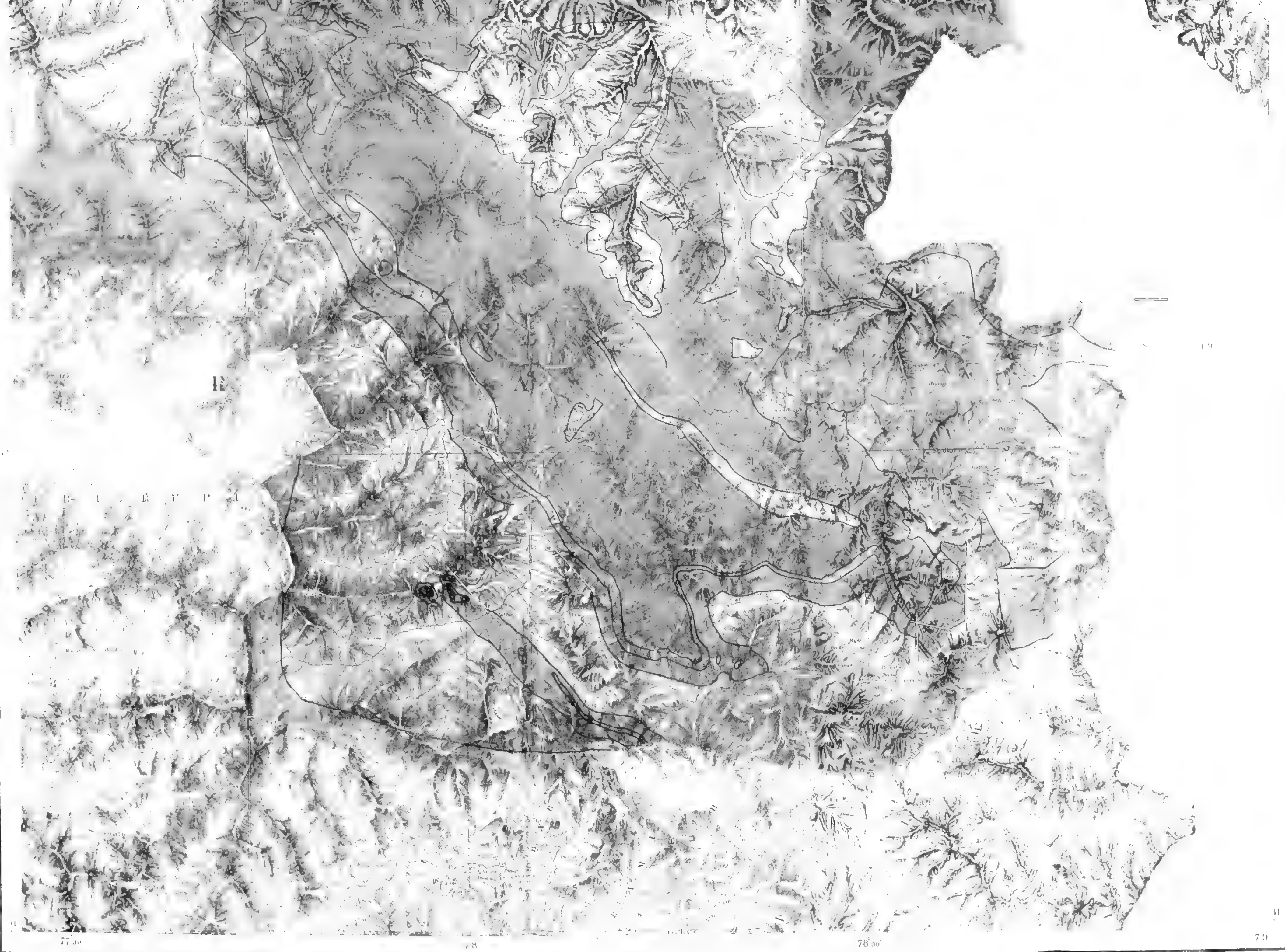
FIG. 2. MATRIX OF PERMIAN CONGLOMERATE, NEAR DANKHAR.



H. H. Hayden, Photo

FIG. 3. MATRIX OF BLAINI BOULDER-SLATE.





GEOLOGICAL MAP OF SPITI, WITH PARTS OF KANAUR AND RUPSHU.

By H. H. Hayden and the late A. von Kraft

NOTICE
OF MEETING

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

N. Y. Academy
OF SCIENCES

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

VOLUME XXXVI, PART 2.

THE GEOLOGY OF THE PROVINCES OF TSANG AND Ü IN
CENTRAL TIBET. *By* H. H. HAYDEN, B.A., B.E., F.G.S.,
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Published by order of the Government of India.

CALCUTTA :

SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY,
27, CHOWRINGHEE ROAD.

LONDON : MESSRS. KEGAN PAUL, TRENCH, TRÜBNER & CO.
BERLIN : MESSRS. FRIEDLANDER UND SOHN.

1907.

CALCUTTA :
GOVERNMENT OF INDIA CENTRAL PRINTING OFFICE,
8, HASTINGS STREET.

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INTRODUCTION.

Until the despatch of the Tibet Frontier Commission in the summer of the year 1903, nothing was known of the geology of the area lying between the northern frontier of Sikkim and Nam Tso (Tengri Nur)¹. At both of these limits fossiliferous rocks had been found, first on the south by Sir Joseph Hooker, who in 1849 discovered limestones, which he regarded as Tertiary in age, on the eastern shore of Tso Lhamo ("Cholamo"),² a small glacial lake at the northern foot of the Drongkhya La, and subsequently, in 1874, by Pandit Nain Singh, of the Survey of India, who collected specimens of *Omphalia trotteri* Fstm.³ at Nam Tso. Nothing, however, was known of the intervening country, until, shortly after the arrival of the mission at Kampa dzong, Mr. Claude White, Political Agent in Sikkim, forwarded to the Geological Survey a number of ammonites characteristic of the Spiti shales. With these were a few fragments of lamellibranchs, which were referred by my colleague, Mr. Vredenburg, to the family of the *Rudistæ*. The importance of this discovery

¹ "Nam Tso" is the Tibetan and "Tengri Nur" the Mongolian name for this lake; since the lake is actually in Tibet the former name is preferable.

² *Himalayan Journals*, II (1854), 177.

³ *Rec. Geol. Surv. Ind.*, X (1871), 21.

was at once recognised and it was decided that a geologist should join the mission at Kampa dzong.

The results of the traverse subsequently made through a considerable part of Central Tibet are embodied in the following pages, which, however, do not claim to give more than the merest outline of the geology of the area passed through, for although, during the early months of peaceful expectancy at Kampa dzong, it was found possible to make a fairly extensive examination of the surrounding country, yet after the transfer of the scene of operations to the Chumbi Valley, the exigencies of a military expedition confined observations almost entirely to the bare line of march.

I must once more record my great indebtedness to Sir F. E. Younghusband, K.C.I.E., who did so much to forward every branch of scientific enquiry and earned, both by his never-failing sympathy, as well as by material aid always so generously given, the deep gratitude of all who were privileged to work under him. My thanks are also due to many members of the mission and escort for frequent assistance in the collection both of geological specimens and of information: I am especially indebted to Messrs. J. C. White, C.I.E., E. H. Walsh, I.C.S., E. C. Wilton, C.M.G., Major C. H. D. Ryder, R.E., D.S.O., Captains W. F. O'Connor, C.I.E., H. M. Cowie, R.E., and R. Lloyd, I.M.S., and Lieutenant F. M. Bailey.

CHAPTER I.

PHYSICAL FEATURES.

1. Mountain Systems.

On the map compiled by Trelawney Saunders and published in Sir Clements Markham's edition of the narratives of Bogle and Manning,¹ the Himálaya mountains are shown, so far as their eastern division is concerned, as consisting of two distinct and continuous ranges lying to the south of the Tsangpo and running parallel to

¹ 2nd edition (1879).

one another, almost due west-east, but coalescing at the point where the Tsangpo takes a sudden bend to the south and cuts its way through the hills to the plains of Assam. To the north of the Tsangpo a third equally well-defined range is shown as the Gangri mountains.

In the second edition of the *Manual of the Geology of India*,¹ Mr. R. D. Oldham has expressed some doubt as to the correctness of this delineation of the Tibetan and Himálayan mountain systems, suggesting that the conditions were possibly by no means so simple as represented. Recent work has thrown new light on this question, and we are now in possession of detailed topographical maps of the whole course of the Tsangpo from its source down to the 91st meridian, while, for the area to the east of this, as far as the bend, the maps prepared by A—k² afford much valuable information. From these it can be seen that, to the north of Kumaon and Nepal, as far east as the 88th meridian, both agree in showing an apparently distinct and well-defined mountain range adhering closely to the Tsangpo and separated from the chain of high snowy peaks by broad and open plains interrupted here and there by transverse spurs. In the publications of the Geological Survey this range is known as the northern range of the Central Himálaya, and it has already been pointed out by Mr. Griesbach and numerous other observers that its crest constitutes the line of water-parting between the small northward-flowing tributaries of the upper Tsangpo and the large rivers which find their way through the southern range of snowy peaks to the Gangetic plain.³

In the neighbourhood of the 88th meridian and from thence eastwards, the orographical conditions have now been found to be by no means so simple as was formerly supposed, for the northern range ceases to exist as a definite unit and merges into a mass of variously

¹ p. 460.

² See *J. B. N. Hennessey*: Report on the Explorations in Great Tibet and Mongolia, made by A—k in 1879–82 (1884).

³ *Mem. Geol. Surv. Ind.*, XXIII (1891), 23.

oriented ridges, intersected by broad valleys and enclosing open plains and extensive lakes, and is not definitely separated from the southern chain of high peaks, its relation to which is somewhat analogous to that of the lower Himalaya to the same range.

Hence in the area dealt with in the present memoir there is only one continuous trough which persists throughout the whole length of Central Tibet: this is the valley of the Tsangpo, which divides the Central Himálaya from the so-called Tibetan ranges, termed by Trelawney Saunders the Gangri mountains and by Hodgson the Nyenchentangla¹ range.

On the west, along the northern frontier of Nepal, a second trough appears to be fairly well marked and continuous, but disappears in Central Tibet, and can be traced only in a series of more or less isolated depressions, such as the Yaru plain and the basin of Kala Tso, lying amongst the complicated system of ranges which here replace the northern range of the Central Himálaya.

The irregularity of the orographic conditions of this area is, as might be expected, reflected in the stratigraphy; still the threefold sub-division into (a) Tibetan, (b) lower Himálayan and crystalline and (c) sub-Himálayan zones is for the most part as clearly marked between Bengal and Lhasa as it is between the Dún and Hundes or between Kalka and Ladak.

The present memoir deals exclusively with the two inner zones, the lower Himálayan and crystalline and the Tibetan. The former of these extends throughout Sikkim and Bhutan and consists chiefly of granite penetrating a series of schists, crystalline limestones

¹ *Gang-ri* is merely a generic term meaning "snowy peak" and its use by the Tibetans is analogous to that of the term "tsang-po" for any large river. Nyen-chen-tang-la—? "Nö-jin-thang-lha" (*Nö-jin*=mountain deities)—is also the name given by Littledale [*Geogr. Journ.*, VII (1896), 467] for the snowy range to the south of Nam Tso (Tengri Nur) culminating in the peak named by him "Charemaru" (? *Tsa-ri*), the height of which he states to be 24,153 feet. This is possibly the peak visible from the hills above Gyantse and also from the Pem-po-go La; its position was fixed from the hills to the north of Lhasa by Major Ryder and the height determined at 23,250 feet.

and granulites, which are probably in part the equivalents of the similar Archæan rocks of the Peninsula and Burma. The complete absence amongst these of fossiliferous sediments leads us to the conclusion that this part of the Himálaya belongs stratigraphically to the Peninsula, and has from earliest Palæozoic times been a land surface, in fact the northern coast of Gondwanaland.

This zone comprises all the highest peaks of the Himálaya, the relics of the snow-clad mountain range which was originally the line of water-parting between the S.-N. and N.-S. drainage systems. Now, however, it has been cut through by the more active rivers of the southern watershed, which have captured much of the watershed of the northward-flowing tributaries of the Tsangpo, and the once continuous range is now merely a series of isolated peaks or groups of peaks, which can, however, be followed from end to end of the Himálaya.

Here and there branches of granite diverge from the main mass of the crystalline zone, and force their way through the sedimentary beds to the north. Throughout the greater part of the Himálaya, such off-shoots are not apparently of great extent: but in the area with which we are at present chiefly concerned, they are both numerous and extensive. The most important of these subordinate intrusions diverges from the central core on the western boundary of Bhutan and Chomolhari and runs towards the north-east, forming the range of snowy peaks which constitutes the water-parting between the drainage flowing northwards to the Tsangpo and lake Yamdrok and the southward-flowing rivers of the highlands of Bhutan.¹

Further off-shoots run from the Lingshi range northwards to Nöjinkangsang and the Karo La, the only group of snowy peaks between Northern Bhutan and the Tsangpo, and a mass of intrusive granite, genetically related to that of the crystalline zone, is found

¹ This range is a perfectly definite orographic unit, but has no name since the Tibetans name only peaks and passes; it might be conveniently called the Lingshi range, from the pass of that name, leading through it from the Tūna plain to Bhutan.

also at Dzamtrang in the valley of the Nyang Chu some sixteen miles to the south of Gyantse. The smaller intrusive masses are not superficially connected with the main granitic core of the crystalline zone, but their close genetic relationship to it renders it probable that they are merely off-shoots from one and the same magma, ramifying along lines of weakness in the folded sedimentary beds. The more intricate the ramification, the more complicated will be the structural conditions and consequently the orography, and it would seem therefore that the change from the comparative simplicity of the northern range of the Himálaya in their central portion to the complexity in the eastern, is due largely to the extensive intrusions of granite along lines of weakness, and that the further we go to the east the more complex will the conditions become, since we approach nearer to the area in which the two great systems of folding, the Himálayan and the Tibeto-Burmese, meet ¹ and in which the structural conditions would naturally be expected to be more highly complicated.

2. Rivers.

To the north of the crystalline zone lies the Tibetan zone, composed chiefly of sediments deposited in the *Tethys*, the Mesozoic sea of Eurasia. In Central Tibet, as elsewhere in the Himálaya, these sedimentary beds are intensely folded. The longitudinal axes of the folds run approximately W.-E., parallel to the Himálayan arc, and thus determine the directions of the main drainage lines—a longitudinal system from west to east and transverse systems from north to south and south to north.

The longitudinal system is represented by the great trough of the Tsangpo which, from its source to at least as far east as the meridian of Lhasa, follows with remarkable accuracy the trend of the Himálayan arc.

Longitudinal system:
the Tsangpo.

At a short distance below Shigatse the river appears to enter a

¹ Suess: *Das Antlitz der Erde*, Vol. I (1892), 590.

series of deep gorges cut through granite and possibly various volcanic rocks, pebbles of which are numerous amongst the river gravels further down : at Chapra the valley rapidly widens and soon becomes from two to four miles broad with numerous river channels and old gravel banks ; sand dunes are seen at Chaksam where the sand is piled against the western side of the hill which stands out prominently in the middle of the valley.¹

Throughout this part of its course the river runs parallel to the strike of the Jurassic slates, but further to the east its relation to the strike of the sedimentary beds is still only a matter of conjecture and at the point at which it bends to the south to cut its way through the mountains, the stratigraphical conditions are, as already stated, probably highly complicated. It has been suggested to me by Mr. R. D. Oldham that the latter part of its course may afford an example of the phenomenon of capture so common in the Himálayan rivers, and that originally the Tsangpo may have continued onwards further to the east, but this and many other geological and geographical problems of absorbing interest must await solution until the unknown country between the Tsangpo and Batang has been visited, here the Himálayan system meets the N.-S. system of the Burmese and eastern Tibetan folds, and here too it should be possible to determine the relationship of the sediments laid down in the Eurasian Mesozoic sea to the older Palæozoic and metamorphic beds found by Szechenyi and Loczy in the ranges of Eastern Tibet and Western China.²

The transverse drainage system comprises several large rivers, including the Lachen and Lachung (which unite at Tsüntang to form the Tista), the Arun (or Yaru) Chu, the Ammo Chu, the Nyang Chu and the Kyi Chu.

¹ These are entirely wind-formed and show the direction of the prevailing winds to be westerly.

² *Wiss. Ergebnisse der Reise der Grafen Bela Szechenyi in Ostasien* ; Bd. I (1893).

The Lachen and Lachung are already well known from the work of Hooker, Blanford and others. They rise on opposite sides of the Drongkhya La, the Lachen from the southern side and the Lachung from Tso Lhamo and the surrounding snow-fields on the north. Both these rivers have been described by Hooker, to whose graphic and accurate account I have nothing to add. His sketch of the country to the north of the Drongkhya La shows admirably the broad open valley through which the Lachen flows for the first few miles, before it turns at Gyangang to cut its way through the moraines and talus from Chomoyumo and Kangchenjhao.

Separated from this valley by the comparatively low ridge running from Chomoyumo to Pauhunri, is the Yaru plain in the centre of which stands Kampa dzong; through this meanders the Yaru river, flowing at first approximately N.-S. but subsequently turning to the west and flowing out through the hills to the west of Mong-go into Nepal. The basin drained by this river is of very considerable extent, but there is reason to suppose that it was formerly even greater than it is now. High up on the hills near Kampa dzong, many hundred feet above the plain, are found patches of old river gravels, containing well-rounded boulders, many of which are of granite and have apparently been derived from Pauhunri and Kangchenjhao. Numerous erratic blocks of granite are also found in the valleys and on the slopes to the west of Tatsang and can only have been derived from the granite peaks to the south. It appears therefore that the glaciers of Pauhunri and Kangchenjhao at one time extended to the north into the Yaru plain, and that the upper valley of the Lachen river originally belonged to this drainage system but has been subsequently captured from it by the gradual cutting back of the head-waters of the Tista. It is even possible that the Yaru river itself may have flowed northward to join the Tsangpo, but of this we have no direct evidence, and the present line of water-parting between the northern and southern transverse drainage is the crest of the range which forms the northern

boundary of the Yaru plain, and runs far to the westward, merging into the northern range of the Central Himālaya.

At the north-east corner of the Yaru plain the line of water-parting suddenly bends round to the south and runs back to Pauhunri, thence east through the Tang La to Chomolhari and continuing thence to the north-east lies on the Lingshi range—the dividing range between Northern Bhutan and Tibet.

Thus the Tang La constitutes the crest of the watershed between the basin of the Nyang Chu and that of the Ammo Chu. The latter river rises in the glaciers of Pauhunri and Chomolhari, one branch draining the Phari plain and the other the Khongbu valley; these unite at Bakcham and flowing through the narrow valley of Chumbi debouch on the plains of Bengal as the main branch of the Torsa.

The largest, in fact the only important, river flowing to the north to join the Tsangpo in this part of Tibet, is the
Nyang Chu. Nyang Chu. Its various branches rise in the glaciers of Chomolhari and the Lingshi range, in the hills to the west of Kala Tso and in the group of peaks in the neighbourhood of the Karo La.

There is no evident connection between this river and the streams falling into Hram Tso and Kala Tso, but near Mangtsa, at about 10 miles to the east of Kala Tso, a stream of considerable volume issues from under the gravel terraces of the plain, and there can be little doubt that its waters are derived from Kala Tso by underground percolation.

The two main branches of the Nyang Chu unite at the southern end of the Gyantse plain. One of these flows north across the strike of the folded and crushed sedimentary beds at Dzamtrang, cutting out a deep and narrow gorge through a mass of granite and other intrusive rocks; the other branch is formed by the union of the Nyiru Chu, deriving its waters from the snowy peaks to the north of Bhutan—the Lingshi range—and the Ralung Chu coming from the glaciers of Nöjinkangsang and surrounding peaks. From Gyantse the river

flows through a broad and fertile valley to Shigatse where it joins the Tsangpo.

To the east of the Karo La most of the streams fall into a basin of internal drainage, in which lies the famous
Rong Chu. Yamdrok lake. The only exception is the Rong Chu, which, rising at a short distance from the north-western shore of the lake, flows through a deep and narrow valley to join the Tsangpo at some distance below Shigatse. The Rong would appear to have been at one time a considerably larger river than it is at present and probably flowed out of Yamdrok Tso; it may still derive some of its water from the lake by percolation through the old moraine material which now dams the outlet (see below, p. 12).

Second only in importance to the Tsangpo, the Kyi Chu rises
Kyi Chu. in the mountains to the east of Lhasa and is joined by various streams flowing from the north and north-west. At Lhasa it flows through a broad, swampy plain spreading out into several channels separated by gravel banks (Pl. 6). Its fall from Lhasa to near Chushü, where it joins the Tsangpo, is a little less than 300 feet: its gradient is thus only about 1 in 600.

3. Lakes.

Like most known Tibetan lakes those of Central Tibet were once much larger than they are now; and if, as is usually supposed, they are still undergoing desiccation, it is probable that, owing to higher rainfall, the rate is not so rapid as in the arid plains of western and northern Tibet.

In the area visited by the mission, the most important lakes are Tso Modretung, Hram Tso, Kala Tso and Yamdrok Tso.

The first of these lies in the north-western corner of the Yaru
Tso Modretung. plain and is fed by rivers from the high range to the north. Its area is about forty square miles and it appears at present to have no outflow, although there is a well-marked channel connecting it with the Yaru river, into which, however, it probably drains by under ground percolation.

Hram Tso occupies the northern part of the great Tūna plain, lying to the north of the Tang La. It is fed by streams flowing in from the surrounding ranges and, unlike most Tibetan lakes, has also, except in the depth of winter when all streams are frozen, a permanent outflow; this escapes through a narrow gorge eroded out of the Jurassic slates at the extreme northern end of the lake at Tsalu, whence a small river runs to Kala Tso, into which it falls near the village of Kalashar.

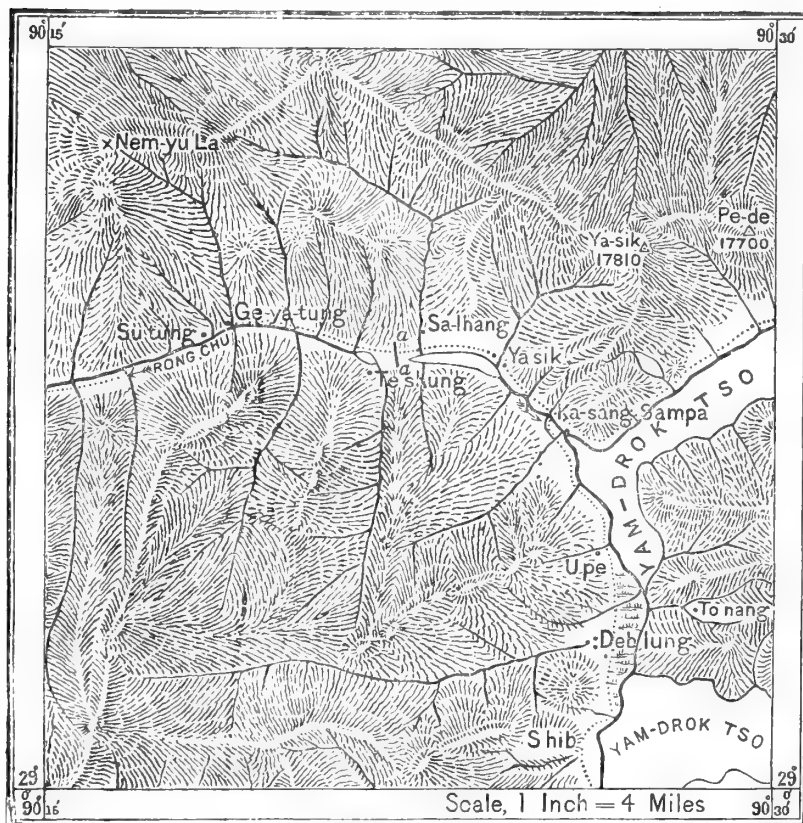
The latter lake lies in an open valley running approximately W.-S.W. to E.-N.E. and some 20 miles long by 4 miles wide; the area of the lake is now only about 17 square miles, but there is ample evidence to prove that it was formerly very much larger. Terraces showing the former shores of the lake can be clearly seen at about 30 feet above its present level, whilst the old bed, now dry, extends far across the plain towards Mangtsa. At about seven miles to the east of the present lake an old river-course, with several terraces, indicates the former outlet; this, however, is now dry and outflow takes place by underground percolation.

Like Kala Tso, Yamdrok Tso has now no outlet. The lake occupies a basin between 600 and 700 square miles in extent, in the centre of which is a mass of hills. In the eastern portion of this basin lies the greater part of the lake, a wide expanse some 30 miles long by 8 miles wide: thence a narrow arm, at one time probably a river valley, runs northward, occupying a deep valley (Pl. 7) and curving round so as to almost completely encircle the central mass of hills. Opposite Nangkartse lies the Dumo Tso, which, although once part of Yamdrok Tso, is now separated from it by strips of low-lying marsh-land.

Numerous old terraces can be seen on the hill-sides above the shores of the lake; they are as a rule rather indistinct, but two still remain well-marked, one being at about 100 feet and the other at 30 feet above the present level. It is evident, therefore, that the lake has contracted in volume, and that at one time it must have completely

encircled the central hill-mass and extended to some height up the mountain sides.

The broad valley running out from Kasang Sampa—a dam partly natural and partly artificial—at the north-west corner of the lake, was evidently the original outlet whence the drainage escaped down the valley of the Rong Chu; this, however, was gradually closed and the Rong no longer rises in Yamdrok Tso, but in a small lake at about 6 miles further to the west-northwest. Between this and Yamdrok is another small lake, whence the water flows back through Kasang Sampa.



Map showing reversal of drainage at head of Rong Chu.

a-a, line of water-parting.

A complete reversal of the drainage has thus taken place and the line of water-parting between the Rong Chu and Yamdrok Tso lies between the villages of Salhang and Teshung.

Numerous small lakes of comparatively recent origin lie among the glaciers and old moraines of Sikkim and Tibet: examples of these are Tso Lhamo, Bam Tso and Gyamtsonang in the Lachen basin, numerous small lakes among the old moraines on the western flanks of the Lingshi range and a small tarn at the end of the great glacier opposite Dzara, the Chinese post-house to the east of the Karo La.

The origin of the Tibetan lakes was formerly ascribed to the damming up of rivers by the débris brought down by side streams, but some years ago an ingenious suggestion was made by Mr. R. D. Oldham that the true explanation might lie in local uplift of the river-bed; hence if the rate of elevation exceeded that of erosion of the river, the stream would be unable to keep its channel open and a lake would consequently be formed. The valley between Yamdrok Tso and Teshung (see wood-cut, p. 12) is broad and open, and the amount of débris brought in from the lateral valleys even when they carried glaciers would have been too insignificant to have arrested the flow of the important river that must once have passed through the Rong valley. If, however, we assume that by a slight local uplift the bed of the river was raised between Yasik and Teshung, the deposition of a comparatively small amount of débris might have been sufficient to result in the formation of a lake. The contrast between the deep and precipitous gorge of the Rong some way below Teshung and the open valley above is a further indication of local elevation having enhanced the erosive power of the river below and diminished it above the line of uplift.

Turning now to Kala Tso we find no evidence of uplift such as is furnished by Yamdrok and the valley of the Rong Chu. The eastern margin of the lake lies many miles from the valley of the Nyang Chu, the intervening area is now covered by fine silt such as is found

around the present shore and all evidence points to the fact that the lake once extended to the river valley at Mangtsa. From this point a broad glaciated valley runs up to the snow-clad peaks on the Bhutan frontier, and the extensive moraines with which it is now filled show that a large glacier once flowed from these peaks to the valley of the Nyang Chu ; this glacier, as it retreated, closed with its moraine the tributary valley of Kala Tso and thus produced a lake, the waters of which stood at a height of about 30 feet above their present level for a period long enough to enable the lake to leave a clearly defined terrace to mark its old shore-line. Once desiccation set in, it appears to have continued steadily and, so far as can be ascertained from local evidence, to be still in progress at the present day. This process is usually attributed to the rise of the main range of the Himalaya and the consequent arrest of the moisture-laden winds of the Indian monsoon, and should it be possible to prove by a series of observations that desiccation is still in progress, this would strengthen the prevalent belief that the Himalayan mountain-system has not yet reached maturity. It would of course be necessary for such observations to extend over a long period of years, but under existing circumstances, there should be no difficulty in establishing gauges both on Hram Tso and Kala Tso. Similar observations might be made on the Rupshu lakes, of which Tso Moriri would probably be the most suitable, and it might even be feasible to extend them to Manasarowar and Rakas Tal.

4. Glaciation.

In Central Tibet, as in all parts of the Himálaya, there is ample evidence to show that glaciation was formerly very much more extensive than at the present day. The old moraines between the Yaru plain and the head-waters of the Lachen have already been referred to. Further to the west, vast moraines extend from the northern slopes of Chomoyumo and from the Naku La far into the Kampa plain, whilst broad spreads of talus and moraine cover the northern slopes of

the Lhonak range for many miles beyond the snouts of the present glaciers: these deposits have been deeply eroded by the existing streams, which have cut out impassable gorges with vertical sides often as much as 300 feet and more in depth.

Similarly from Pauhunri, Chomolhari and the Lingshi range, old moraines spread out into the Tūna plain, and show that the small glaciers on the northern sides of these mountains are but the shrunk relics of what must once have been a great ice-sheet almost completely covering the slopes of the culminating range of the Himālaya and extending far into the neighbouring plains and valleys. A good example of this can be seen in the upper valley of the Nyang Chu at Mangtsa, where the bottom and sides of the valley, as well as the plain to the south, are covered with a thick mantle of clay and boulders deposited by the retreating glaciers. These deposits, composed chiefly of granite and limestone brought from the Lingshi range, have now been cut by the river into a series of terraces of which as many as five or six can be seen on the right side of the valley.

5. Hot Springs.

The hot springs of the Lachung valley were described more than half a century ago by Sir Joseph Hooker, who found them to have temperatures varying from 110° to 116° . Very similar, but apparently more extensive, springs occur some miles further to the east, in the Khongbu valley at about one mile above the village of Yoja. The water, which issues from joints in the granite, is distinctly sulphurous and its temperature is probably about the same as that of the Lachung springs.¹ There are altogether thirteen springs, several of which are used as baths; these are greatly frequented for medicinal purposes by both Tibetans and Chinese, chiefly for the cure of skin diseases and rheumatism, but each bath is supposed to have properties not possessed by the others and to be specially

¹ Unfortunately my thermometer had been broken and I was unable to verify this.

adapted for the treatment of a specific disease or set of diseases, the particular bath employed thus depending on the nature of the malady to be treated.

Hot springs also occur at about five miles to the north-northeast of Kampa dzong and at Khangma in the valley of the Nyang Chu. The springs of Kampa dzong are considerably hotter than any others known in this area: their temperature varies from 140° F. to 175° F. and was reported in one instance to have been as much as 186° . They issue from the Jurassic beds in the valley of the Yaru river, and like those of Lachung and Yoja have a strong sulphurous smell.

Extensive deposits of both calcareous and siliceous tufa surround the springs and sometimes take the form of a series of small terraces. Beautiful crystals of yellow calcite are also found in cavities in the calcareous tufa.

The Khangma springs are situated on a broad river-terrace at about $\frac{3}{4}$ mile below the village of Khangma on the right bank of the Nyang Chu. Large masses of travertine occur on both sides of the river and prove that the springs must at one time have been very much more extensive than they are at present. Very few of these springs are now active, but the sites of many now extinct can be traced in the little cones dotted about the surface of the ground. The cones of some of those now active are as much as four or five feet in height, the water bubbling up gently or lying quiescent in a small crater in the apex of the cone. In some instances there is no overflow although the water in the crater is warm. It is just possible that these apparently quiescent springs may be miniature geysers, but I saw no signs of periodic movement of the water during the short space of time I was able to devote to their examination.

Both the Khangma springs and those of Kampa dzong rise along lines of fracture of the rocks, the latter springs being situated on the important dip-fault which cuts through the Cretaceous beds on the ridge behind the fort, whilst the Jurassic beds at Khangma are intensely folded and a fault can be seen in the hills on either side of the river and passing through the site of the springs.

CHAPTER II.

THE CRYSTALLINE ZONE.

It has already been pointed out that the whole area between the southern boundary of Sikkim and Lhasa falls into two broad sub-divisions, an older crystalline and metamorphic, and a younger, sedimentary zone.

The crystalline and metamorphic zone covers the greater part of Sikkim and extends eastward through the Chumbi valley into Bhutan. The rocks of this zone have been described by various authors, first by Sir Joseph Hooker,¹ subsequently by Mr. Blanford,² Mr. Mallet³ and Mr. Bose,⁴ and recently by Professor E. J. Garwood, whose paper, issued as an appendix to Mr. D. W. Freshfield's "Round Kangchenjunga" (1903), marks an important advance in our detailed knowledge of the geology and physical features of upper Sikkim. Professor Garwood has recognised the great difficulty involved in any attempt to map separately the component elements of the crystalline complex and has therefore merely indicated on the topographical map the localities at which the more prominent lithological types occur, wisely avoiding any attempt to indicate petrographical boundaries.

Professor Garwood has shown that the greater part of upper Sikkim consists of gneiss and granite, of which all the higher peaks of this part of the Himálaya are formed. The gneiss, which is described in detail, is referred in great part to a foliated granite, a conclusion with which my scanty observations made during a very rapid march along the Lachen valley are entirely in accord. In addition to the gneiss, metamorphic beds, some of which at least are of sedimentary origin, are found along the valley of the Tista and Lachen rivers; they

¹ *Himálayan Journals*, II (1854).

² *Journ. As. Soc. Beng.*, XL (1871), pt. II, 367—420; XLI (1872), pt. II, 30—71.

³ *Mem. Geol. Surv. Ind.*, XI (1874), pt. I.

⁴ *Rec. Geol. Surv. Ind.*, XXIV (1891), 46, 217.

consist chiefly of garnetiferous mica schist, which is frequently found in contact with the gneiss and granite; less common are scapolite-granulites, crystalline limestone, quartzite and graphitic gneiss.

On the road from Gangtok to Tangu, crystalline limestone was observed at three localities, *viz.* :—

- (1) on the right bank of the Tista, at about $1\frac{1}{4}$ miles above the Tung bridge, and thence at intervals up to Tsüntang ;
- (2) on the left bank of the Lachen river, at about 3 miles above Tsüntang ;
- (3) on the left bank of the Lachen, near Pangri, half-way between Lamteng and Tallum Samdong.

The first outcrop of limestone seen above Tung is a vertical bed about 30 feet thick and consists of a whitish and pale-grey banded rock which, if polished, should afford a handsome ornamental stone.

The limestone above Tsüntang, and that near Pangri, is a white crystalline rock composed of calcite and dolomite in approximately equal proportions, with various accessory minerals which include scapolite, diopside, chondrodite, spinel, sphene and, in some instances, quartz, feldspar and actinolite. Near Tsüntang, the limestone is associated with the quartzite recorded on Professor Garwood's map, and with an interesting series of pyroxene-scapolite granulites, and at Pangri it appears to be connected with a graphitic biotite-garnet-sillimanite gneiss. With the exception of the quartzite, none of these rocks are mentioned by Professor Garwood, but he describes two interesting rocks, to which he ascribes a sedimentary origin, from the western face of Pandim. One of these is composed chiefly of garnet, epidote and hornblende, but contains also quartz, scapolite, calcite and augite, and is thus probably genetically related to the scapolite granulites of Tsüntang.

Owing to the highly complicated nature of the tectonic conditions prevailing in this area and the density of the vegetation covering the mountain sides, it was impossible to ascertain, during a rapid traverse, the mutual relations of the several members of this crystalline

series, which so far as we know at present, has no counterpart in the Himálaya,¹ but has, on the other hand, many points of resemblance to the oldest member of the Archæan group in the Peninsula and Burma. At the same time the similarity of the Daling series to certain facies of the Dharwar system further emphasises the striking analogy between the unfossiliferous rocks of Sikkim and the Archæan group of the Peninsula.

In the Chumbi valley, as in Sikkim, the prevailing rock is foliated biotite-granite, which forms the ranges on either side of the Ammo Chu and runs on eastwards into Bhutan. Near the junction of the Ammo and Khongbu rivers, it includes micaceous and quartzose schists, possibly in part of sedimentary origin.²

Higher up the valley at about a mile and a half below Gautang a band of dark grey limestone crosses the road, striking approximately east-west; but the sedimentary rocks in this part of the valley are of no great extent and soon give place again to granite which extends to within a short distance of Dothak, where it is found in contact with the stratified rocks of the Phari plain.

CHAPTER III.

PRE-JURASSIC SEDIMENTARIES.

A glance at the geological map will show that throughout Sikkim the northern boundary of the crystalline zone adheres closely to the northern slopes of the highest peaks, thus enclosing the Kinchinjunga group, Chomoyumo, Kangchenjha and Pauhunri, but to the east of the last-named, it turns southward and runs below the Khongbu valley and the Phari plain into Bhutan. To the north-east of Phari the crystallines re-appear, forming the peak of Chomolhari,—which is

¹ Since the above was written pyroxenic gneisses exactly resembling those of the Central Provinces have been found by my colleague, Mr. L. L. Fermor, near the Pindari glacier in Kumaon.

² The mica schists of the Chumbi valley are stated by Col. Waddell [*"Lhasa and its Mysteries"* (1905), p. 492], to be merely micaceous varieties of the gneissose granite; much of the schist however is a garnet-sericite rock, such as is usually regarded as the result of the metamorphism of an argillaceous rock of sedimentary origin.

composed of biotite gneiss with intrusive bands of schorl granite—and run thence through the mountain ranges to the north of Bhutan.

1. The Khongbu series.

The bay formed by this bend in the boundary of the crystalline zone contains the only stratified rocks of pre-Jurassic age encountered during the recent expedition. The oldest of these occur in the lower part of the Khongbu valley, forming the high ridges on either side of Talung and extending as far as the upper reaches of the Ammo Chu. On the north and south and probably on the west¹ they are in direct contact with the granite, but on the east they abut against a younger sedimentary series from which they are separated by an important fault which can be traced from Dothak almost to the Tang La and has determined the course of the upper part of the Ammo Chu. On the west of this fault are the Khongbu beds, consisting of slate and schist with flaggy calcareous bands, often crystalline. These rocks are all apparently devoid of organic remains and quite distinct from, and probably much older than, anything seen on the east of the fault. They are less highly metamorphosed and less disturbed than the parashists and paragneisses of the crystalline zone, but very decidedly more so than the neighbouring rocks of Dothak and the Phari plain.

In the preliminary note published in the *Records* (XXXII, pt. 2), the Khongbu beds were referred doubtfully to the Palæozoic group, but subsequent detailed consideration of their characters points rather to a correlation with the unfossiliferous pre-Cambrian rocks of the more westerly parts of the Himálaya.

2. The Dothak series.

To the east of the Dothak-Tang La fault, on the left bank of the Ammo Chu, a distinctly younger series of sedimentary rocks extends from the northern boundary of the Chumbi granite throughout the

¹ Their western boundary, which appears to be on the range separating the Lachung and Khongbu valleys, could not be visited.

ranges separating upper Chumbi and the Phari plain from Bhutan. These rocks consist of limestone, sandstone, quartzite, slate and shale; limestone predominates, forming steep cliffs at Dothak and throughout the neighbouring ridges. Except in the immediate neighbourhood of the granite, where the rocks have been subjected to contact-metamorphism, the whole series is one of unmistakeably sedimentary origin; the beds have a general northerly dip, thus passing beneath the Phari plain, and so underlying the Jurassic slates which extend from near Kamparab to Phari dzong.

Unfortunately only the most cursory examination could be made of this series, which appears to cover such a large area and to be at the same time of great interest. Among the hills above Dothak at about a mile to the east of the river a small stream has exposed a section, perhaps 1,500 feet thick, of what appear to be the middle beds of the series. These consist of limestones below with arenaceous and argillaceous beds above; they have all suffered considerably from crushing, and any fossils that the rocks may have originally contained are now for the most part represented by fragments of crystalline calcite. Near the top of the section, however, casts of ammonites were found in a thin band of hard quartzite and a few fragments of bivalve shells in an indurated slate; these were all quite undeterminable even generically, consequently the age of this part of the series is unknown, and can only be conjectured from observations made on higher beds seen in a valley opening on to the Phari plain at a short distance to the east of Agang, and which are regarded as of liassic age (see p. 26).

Although it was not found possible to examine the hills between the Dothak section and the valley east of Agang, yet from what could be seen from the road at Kamparab, it appears safe to conclude that there is a continuous series from the altered sedimentary beds in contact with the Chumbi granite up to the supposed liassic limestones. This series must therefore include at least part of the Trias, and since its total thickness must be several thousand feet it may extend even lower down in the stratigraphical scale, including

not only the whole of the Trias but possibly one or more of the Palæozoic systems. It is very unfortunate that, owing to the conditions prevailing at the time of my visit to this area, it was impossible to examine these beds in detail, but it is to be hoped that at some future date they may be rendered accessible and an exhaustive study may be made of this small patch of sedimentary rocks. The importance of their bearing on Himálayan geology can hardly be exaggerated, for at present they constitute the only outcrop of undoubted pre-Jurassic sedimentary beds of Tibetan facies known to occur between Byans and the Subansiri river to the north of Assam.¹

The total area covered by the Dothak series is very considerable, and probably extends throughout the ranges lying between Dothak and the Phari plain on the one side, and the valley of Punakha in Bhutan on the other.

The only fossils noticed in the series were found in the section near Dothak, already described, and on a limestone ridge on the south side of the Tremo La. **Trias (?) near Phari.** In the latter locality the fossils consisted of fragments of bivalves, but none of those found in the course of a rapid examination of the beds were determinable; since, however, out of three localities visited under circumstances which precluded more than a very hurried examination, two afforded fragmentary fossils from the Dothak series and the third determinable brachiopods from the beds immediately overlying that series, it is reasonable to suppose that a more careful survey of the hills to the south of Phari would offer a fair prospect of a successful determination of their stratigraphical position.

The gradual thinning out of the Trias from a total thickness of over 4,000 feet in Spiti on the west to 2,500 feet in Byans on the east is one of the most interesting points recently established in Himálayan

¹ The presence of Permo-Carboniferous beds in the valley of the Subansiri has been inferred from boulders of fossiliferous limestone found near the mouth of that river by Mr. J. M. Maclaren (*Rec. Geol. Surv. Ind.*, XXXI, p. 186; XXXII, p. 190).

geology, and it is greatly to be deplored that it is not possible to extend observations eastwards through Nepal and Bhutan. Under present circumstances the value of the Dothak series is still further enhanced, since it constitutes the only known outcrop of presumably Triassic rocks throughout the whole extent of the eastern Himálaya.

Although the Dothak series is the only one met with during the recent expedition that can be safely asserted to include part at least of the Triassic system, there is another area considerably further to the west in which that system is probably represented. This is the snowy range which runs from Chomoyumo westwards to the frontier of Nepal, and which forms the northern boundary of the valley of Lhonak.¹ Unfortunately this range could not be visited from Kampa dzong, but an excursion along its northern slopes from the neighbourhood of the Naku La to the village of Mong-go, indicated the possible value of a careful examination of the range. The line followed lay across the northern slopes which form a wide inclined plane of glacial débris, cut into cañons, often several hundred feet deep, by the streams flowing from the snow-fields to join the Yaru river: the beds of the streams are full of rounded boulders of dark grey limestone, quite unlike any of the Jurassic or younger rocks and curiously like the Upper Triassic limestones of other parts of the Himálaya. No fossils were found in the boulders of this limestone, and lithological resemblance in two such widely separated areas as Spiti and Lhonak, especially in view of the dissimilarity in the intermediate areas, is of no value as a means of correlation.

To the north of the range are shales and limestones, the former of lower Jurassic age, and as the limestones of the range appear to dip to the north they are presumably the older, and it is therefore possible that Triassic beds may occur among them.

This view, however, is not confirmed by the very interesting observations made in the Lhonak valley by Professor
Mesozoic beds in Lhonak. Garwood, who found a series of altered limestones and sandstones at the head of the Langpo Chu, to the south

¹ For convenience of reference this may be called the Lhonak range.

of the Chorten Nyima La. The only fossils obtained by Professor Garwood were crinoid stems, which led him to identify these beds with the Tso Lhamo limestone described by Hooker¹; but since both of these occurrences have not as yet been visited by one and the same observer, their identity cannot be considered as definitely established, though undoubtedly probable. The Tso Lhamo limestone again bears an equally strong resemblance to a similarly small outcrop occurring among the Jurassic beds of the Phari plain near Agang²; consequently, if all three are regarded as equivalent to one another the Lhonak limestone must also be of Jurassic age. The only objection to this view is the apparent position of that limestone with regard to the lower Jurassic beds of the Yaru plain, but the moraines on the northern slopes of the range may quite possibly hide one or more faults, and it is only by a visit to the Lhonak valley that the matter can be decided.

For the present, therefore, the age of the rocks forming the range between Lhonak and Tibet must remain an open question, but in spite of some apparent evidence to the contrary I am inclined to think that it is in part Triassic.

CHAPTER IV.

THE JURASSIC SYSTEM.

By far the most striking feature of the geology of southern Tibet is the enormous extent of the Jurassic system, which is exposed with little interruption over an area of many thousand square miles extending from the northern flanks of the Himálaya to the Tsangpo—probably even to Nam Tso—and from the western boundaries of the Yaru plain to beyond Yamdrok Tso: to the west it probably

¹ *Himálayan Journals*, II (1854), 177.

² For further particulars see below, p. 26.

extends more or less continuously along the northern frontier of Nepal to Ngari Khorsum, while on the east nothing is known of the country beyond Yamdrok Tso, but it is not improbable that the Jurassic beds will be found to extend to the N.-S. bend of the Tsangpo or even beyond this to the flanks of the great meridional mountain ranges of eastern Tibet.

The general lithological characters of the system are not unlike those prevailing in other parts of the Himálaya. In both cases the upper beds are wholly free from limestone, but whereas in the western areas the lower and middle Jurassic rocks are entirely calcareous, in the east they are only partially so, and even among the lower beds sandstone and shale are the predominant types. Except in the Phari plain, their southern boundary is formed by the granite of the crystalline zone, but since the junction runs along the slopes of the granite hills, it is usually obscured by talus or moraines; near Gyangang, however, and on the Kongra La the slates appear to pass through schistose and gneissose rocks into the foliated granite. Not only are the lower beds metamorphosed but they are also considerably disturbed, and owing to the further complications introduced by the numerous moraines, observations along the northern frontier of Sikkim could be made only on disconnected patches, which, however, when taken in conjunction with other occurrences near Kampa dzong and in the Phari plain can be correlated with sufficient approximation to certainty to furnish a fairly complete synthesis of a considerable part of the system.

The most convenient method of treating these isolated occurrences, will be to describe each in detail, and then attempt to correlate them with one another.

For this purpose the most important localities are :—

- a.* Agang in the Phari plain.
- b.* Tso Lhamo.
- c.* Kongra La.
- d.* Naku La to Kampa dzong.

(a) Agang and the Phari plain.

This locality has already been referred to above (p. 21) in connection with the Dothak series. At a short distance to the east of Agang a small valley opens on to the Phari plain ; on the right side of the entrance an isolated outcrop of limestone occurs, underlain by dark slates with some quartzite. At about a mile above the mouth of the valley two streams join, the one coming from the north-east and the other from the south-west ; on the right side of the latter is a low ridge capped by thin-bedded limestone which contains a few fossils ; these are unfortunately rather badly preserved, while the matrix is so hard that it is very difficult to extract them. Only a very cursory examination could be made of the outcrop, and consequently very few specimens were collected ; these include a number of small brachiopods, which appear to belong either to liassic or rhætic (Dachstein) species and comprise a *Waldheimia* either identical with, or closely allied to, *W. resupinata* Sow., species of *Rhynchonella*, *Spiriferina* and *Spirigera*.

This limestone appears to pass down into the extensive series of calcareous shale and limestone which forms the hills to the east of Kamparab and Dothak ("Dothak series"). Lower down the valley on the left bank of the stream just mentioned several blocks of coral limestone were found ; their relations to the brachiopod limestone could not be definitely ascertained, but they appear to occur between it and the overlying slates. The slates are exposed on the right side of the valley ; they are much disturbed and crushed, but yielded an impression of an ammonite and some small lamellibranchs.

At the mouth of the valley two small outcrops of limestone occur in the slate. This dips at high angles to the north and, like the slate, is greatly crushed, the fossils having been almost completely obliterated ; crinoid stems, however, are very numerous, but being entirely changed into crystalline calcite, are not determinable. Here the valley debouches on to the Phari plain and the section ends.

As observed in this locality, then, the sequence is—in descending order—

4. Crinoid limestone.
3. Slate and quartzite.
2. Coral limestones (position doubtful).
1. Brachiopod limestone and upper beds of Dothak series.

Nos. 1 and 2 are probably Jurassic (lias), while No. 3 is almost certainly so.

Between this valley and the Tremo La, numerous similar valleys open into the Phari plain; the low hills on either side of these appear to be invariably composed of slate or shale, which dips towards the plain, the strike thus bending round from approximately E.NE.-W.SW. on the south to nearly N.-S. on the eastern side of the plain. Unfortunately none of these intermediate valleys could be visited, but the sequence of beds in them is probably similar to that just described.

The hillmass which stands out prominently in the middle of the plain is composed of slate and quartzite and is cut off on all sides from the surrounding rocks. Its western boundary is the important Dothak-Tang La fault already mentioned (*supra* p. 20). On all other sides a belt of recent deposits separates it from the neighbouring spurs, but its component rocks can be unhesitatingly referred on lithological grounds to the Jurassic system.

To the north-west of this hill, on the right bank of the river limestones again appear, dipping to the north-west. They are separated from the Khongbu series by the Dothak-Tang La fault but their relation to the beds of the central hill is not apparent from their position and dip they are probably younger, but the junction, which is obscured by the recent deposits of the river valley may be a faulted one; they have, however, been referred provisionally to the Jurassic system. Like all the other sedimentary rocks of this neighbourhood they are crushed and disturbed, no doubt owing to the proximity of the

granite mass of Pauhunri which sends out off-shoots across the head of the Khongbu valley to the edge of the Phari plain. They have consequently yielded no determinable fossils, although they contain numerous traces of bivalves and brachiopods. Boulders of a similar limestone are found in the valleys to the west of Chugya, among the moraines which form the lower hills extending to the Tang La and Pauhunri. These boulders are frequently fossiliferous, but no determinable specimens could be found in them.

The shaly beds on which Phari Fort stands and an outcrop of similar rock on the plain to the east of the Fort also probably belong to the Jurassic system, while the range running from the Tremo La to Chomolhari is probably composed in part of the same system, but this has not been definitely ascertained.

The probable sequence in this area may therefore be summarised as follows—in descending order—

7. Slate and shale.
6. Upper limestone.
5. Slate and quartzite.
4. Crinoid limestone.
3. Slate and quartzite.
2. Coral limestone.
1. Brachiopod limestone.
Dothak series.

(b) Tso Lhamo.

This exposure of shale and limestone seen on the east side of Tso Lhamo, at the foot of the Drongkhyia La, has already been described by Sir Joseph Hooker, who referred it with some hesitation to the Tertiary system, on account of the presence in the limestone of small bodies resembling nummulites¹; Sir Joseph Hooker, however, draws attention to the bad state of preservation of the specimens and leaves their identity open to doubt.

¹ *Himalayan Journals*, II (1854), 177.

This small patch of rock is quite isolated and crops out from among masses of talus and old moraine material. The nearest rocks found *in situ* are the altered beds of the Drongkhya La and a series of more or less altered slates, shale and quartzite forming a small group of hills on the opposite side of the lake and belonging to the series of Jurassic beds which extend from the Kongra La to Kampa dzong. The outcrop consists of black shale overlain by beds of shale and flaggy sandstone, followed by the supposed "nummulitic" limestone which is in turn overlain by hard dark limestone with crinoid stems; these have been altered into white crystalline calcite and consequently show no structural details. All the beds dip at moderately high angles to the north (see Pl. 3, fig. 1).

No similar rocks have been observed anywhere in the neighbourhood, but in the range of hills on which Kampa dzong stands a bed occurs high up in the Cretaceous system, which, in macroscopic characters, is apparently identical with the "nummulitic" limestone of Tso Lhamo; so great is the similarity of the two that the Tso Lhamo rock was unhesitatingly referred by me to the Cretaceous system, in spite of its anomalous position, many miles from other Cretaceous rocks and apparently among the lower beds of the Jurassic system. The Cretaceous rock referred to also resembles nummulitic limestone, but is in reality composed of *Orbitoides* sp. which occur as dark circular and ovoid patches in a bluish grey matrix. In the field therefore the Tso Lhamo rock was referred to the *Orbitoides* limestone, and it was only by means of the microscope that its true character was discerned. Instead of the beautiful structure shown by the foraminifera of the Cretaceous rock, the ovoid patches of the Tso Lhamo limestone proved to be chiefly oolitic grains and showed no trace of foraminifera. No grounds therefore exist for referring this rock either to the Cretaceous or Tertiary system, and since the only beds exposed anywhere near it are Jurassic slates it seems more natural to refer it to that system, and to correlate the crinoid limestone of Tso Lhamo with that of Agang in the Phari plain. In addition to the crinoid stems a few very

small and fragmentary fossils were observed in the rock: these are apparently lamellibranchs (of which one may belong to the genus *Trigonia*) and *Bryozoa*.

If we turn now to the crinoid limestone of the Lhonak valley, we find that although macroscopically it may resemble that of Tso Lhamo, yet its microscopic characters, as described by Professor Garwood,¹ are quite distinct. Stratigraphically it would also appear to occur at a considerable distance below the Jurassic beds of the Yaru plain.² Owing, however, to our ignorance of the conditions prevailing under the moraines to the north of the Lhonak range, no great weight can be attached to this consideration, and if Professor Garwood is correct in identifying his crinoid limestone with that of Tso Lhamo, the probabilities seem in favour of its being Jurassic rather than Palæozoic as suggested by him.³

(c) Kongra La.

Where the Lachen river, rising from the Drongkhya peaks, skirts the northern flanks of Kangchenjha, it flows approximately E.-W. through a broad and open valley: to the south are moraines from the granite peaks, but to the north is a comparatively low range of hills extending from the northern slopes of Chomoyumo to Pauhunri: over these run the passes—Kongra and Sibü on the west and Bam Tso on the east—which lead from the valley of the Lachen into Tibet; they have already been mentioned by Hooker⁴ as consisting of red and

¹ *op. cit.* p. 288.

² See *supra* p. 24.

³ *op. cit.* p. 293.

⁴ It is evident from Sir Joseph Hooker's description of what he calls the Kongralama pass and from the omission of any reference to Gyamtsonang, the lake at the foot of the true Kongra La, that he was misled by the Tibetans into believing that Gyangang, which is in reality some miles lower down the valley, was the Kongra La. *Him. Journ.*, II, 154, 155.

black slates, sandstones and conglomerates, dipping to the north: these have been more or less altered by the neighbouring granite, and are for the most part unfossiliferous. The only fossils met with occurred in a loose block of quartzite, found lying near the road a few hundred yards to the north of Gyamtsonang: this block must have been derived from one of the eastern spurs of Chomoyumo and consists of hard quartzite with crinoid stems and remains of brachiopods: the fossils, which are partly composed of soft limonitic material, are poorly preserved and are indeed merely casts. They include a species of *Rhynchonella*, resembling *Rh. quadriplicata* Zieten.

From Gyamtsonang the road gradually ascends on to a mass of blocks of granite and quartzite, which have been brought down from Chomoyumo and its north-eastern spurs: thence a short ascent to the Kongra La brings into view the rolling hills of the Yaru plain bounded on the far north by black jagged ridges of slate and snow-capped granite peaks which form the watershed between the Yaru river and the northward-flowing tributaries of the Nyang Chu and the Tsangpo.

From the Kongra La the road crosses a flat ridge for some two miles, then descends from the Sibu La to Giri. At first the prevailing rock is slate talus from the northern flanks of Chomoyumo, but near the Sibu La the hills are formed of old moraines of granite and quartzite, relics of a time when the drainage from the granite zone flowed northwards to the Yaru. Below the Sibu La, far to the east and west, are undulating hills of shale, thrown into gentle folds, with here and there an isolated mass of limestone; but most conspicuous of all is the southern scarp of the Kampa ridge, a synclinal of hard Cretaceous and Tertiary beds standing prominently out above the soft and easily weathered Jurassic shales.

From the Lachen valley then the sequence is as follows: below are the conglomerates, quartzites and slates of the Chomoyumo spurs and the Kongra La: these dip to the north and eventually disappear under the moraines of the Sibu La. East of the descent from the Sibu La to Giri, a small group of hills is composed of dark shales,

with many bands of concretions, eminently suited for the preservation of fossils, which, however, only appear in the highest beds, the eastern representatives of the Spiti shales; these contain fragmentary ammonites, similar to those collected by Mr. Claude White in the hills between Giri and Kampa dzong. Above the Spiti shales on the left bank of the Giri river is a contorted series of limestone which presumably belongs to the Cretaceous system. Immediately to the north of this the valley of the Giri river marks an important line of faulting running E.-W., which brings up on the north side of the river. Jurassic quartzites and slates overlain by Spiti shales, which continue northward almost to the Kampa ridge (see Pl. 8, fig. 1). The above sequence may be tabulated as follows in descending order:

- | | |
|-----------|---|
| Limestone | (? Neocomian.) |
| 4. | Dark shales with ammonites (Spiti shales.) |
| 3. | „ „ without fossils. |
| 2. | ? ? (hidden by moraines). |
| 1. | Slate, quartzite and conglomerate with <i>Rhynchonella</i> cf. <i>quadriplicata</i> Ziet. and crinoids. |

(d) Naku La to Kampa dzong.

Turning now from the eastern to the western side of Chomoyumo, we find that a high snow-clad range trending first to the south-west then to the west separates Sikkim from Tibet; this has already been referred to as the Lhonak range. Immediately to the west of Chomoyumo this range is crossed by the Naku La. To the north of the pass the rocks are hidden by talus and moraines, composed of granite blocks derived from the central mass of Chomoyumo; near the foot of the slope which is several miles in length, a ridge of slate and quartzite stands out prominently above the plain; the beds of this ridge appear to be the westerly continuation of the slates and quartzites which form the northern spurs of Chomoyumo. To the north they are overlain by somewhat less altered slate with quartzite and a narrow band of limestone gradually passing up into upper Jurassic rocks and Spiti shales, which extend almost to Kampa dzong.

Among these beds the limestone is by far the most important; it is found on the left bank of a small stream at an old ruin known as Mekyigünru, near Lungma "droksa,"¹ eight miles to the south of Kampa dzong (Pl. 9, fig. 2).

The total thickness of the band is only about 50 feet, but the rock is highly fossiliferous, and, considering its proximity to the granite of Chomoyumo, the fossils are wonderfully well preserved. They include lamellibranchs, brachiopods, cephalopods and gastropods, and are of great interest and value as furnishing a definite horizon in the Jurassic system. They have not yet been worked out in detail, but the following list includes the leading genera and a few characteristic species:

CEPHALOPODA.

Harpoceras (*Dorsetensia*) cf. *complanatum* Buckman.

„ several other species.

Stepheoceras cf. *humphresianum* Sow.

Nautilus sp.

Belemnites sp.

BRACHIOPODA.

Rhynchonella quadriplicata Ziet.

„ *variabilis* Schloth.

„ other species.

Terebratula cf. *ventricosa* Ziet.

LAMELLIBRANCHIATA.

Trigonia costata Park.

„ sp.

Pecten sp.

Pholodomya sp.

? *Lima pectiniiformis* Schloth.

Ostrea sp.

Pleuromya (*Myacites*) cf. *adjectus* Phill.

¹ "Droksa" = summer grazing-ground.

² These will probably be found to include other genera, such as *Sonninta* Buckman.

The lower beds are characterised by the presence of large numbers of lamellibranchs, of which *Trigonia costata* is especially noticeable, occurring in great quantity in an arenaceous band about 20 feet above the base of the limestone.

Brachiopods are apparently absent from the lowest beds and are especially characteristic of the middle of the series, while the cephalopods (ammonites, nautili and belemnites) were found only in the highest beds.

Although it has so far been possible to determine only a few of the Lungma fossils, there is little doubt that they should be referred to the Inferior Oolite of Europe. Unfortunately this fossiliferous series has not been definitely recognised in any other locality, although the E.-W. strike would lead one to expect to find it elsewhere along the southern edge of the Yaru plain, but, owing partly to faults and partly to extensive talus fans and moraines, no other outcrops were found in the area examined: probably, however, it reappears in the hills to the west of the Yaru plain which form the boundary between Tibet and Nepal, and which, owing to political considerations, were not accessible.

The lower slates exposed on the ridge¹ at the foot of the ascent to the Naku La contain a few traces of fossils, including a small *Pecten* sp.

The slates and shales which overlies the limestone also contain traces of fossils, but nothing determinable was found in the beds between the Lungma section and the Spiti shales near Kampa dzong. Even in the latter the fossils are scarce and very badly preserved and not comparable to those found in the more westerly sections of Garhwal and Spiti.

With the exception of the Cretaceous series of the Kampa ridge no system other than the Jurassic is represented in any part of the Yaru plain visited: and, as elsewhere in Southern Tibet, the great extent of this system is most remarkable.

¹The pass crossing this ridge is known as the Sokar La.

Synthesis of Jurassic system.

Before passing on to the rest of the area traversed during the recent expedition, it will be advisable to summarise the results of the examination of the exposures described above and, so far as possible, piece together the disjointed parts into one consecutive whole: this is rendered particularly difficult by the isolated character of the exposures, which can so rarely be traced from one locality to another, partly on account of faulting, which, in spite of the gentle dip of many of the beds of the Yaru plain, is nevertheless very considerable in places, as along the Giri river and again in the hills behind Kampa dzong; partly also owing to the extensive moraines and talus slopes which, except near Lungma, obscure all the older beds. Fortunately the section from the slates below the Lungma limestone is fairly continuous up to the Spiti shales, and we have thus two known horizons on which to base a synthesis of a considerable part of the system: but between the limestone with *Trigonia costata* and the Spiti shales no determinable fossils have been found, and we are thus compelled to group the intervening beds into a single series presumably comprising all the intermediate stages, that is to say the remainder of the middle, and all except the uppermost, Jurassic.

With the lower beds it is more difficult to deal: those underlying the Lungma limestone are probably continuous with the slates and quartzites of the Kongra La, while the Tso Lhamo limestone is almost certainly older than these.

The Jurassic series of the Lachen-Kampa dzong area may therefore be tentatively classified as follows:—

Spiti shales	Upper Jurassic.
Black and grey shale and quartzite	{ Partly upper „ middle } Jurassic.
Lungma limestone	Middle Jurassic.
Slate, quartzite and conglomerate	{ Lias.
Tso Lhamo limestone	

(156)

Although, with the meagre data available, any attempt to correlate the Jurassic system of the Phari area with that of Kampa dzong is perhaps of doubtful utility, yet it is advisable to draw attention to the mutual resemblance of parts of the two series: thus crinoid limestones occur in both areas and are in each case probably overlain by slates and quartzites, which, in one area certainly and in the other very probably, are succeeded by fossiliferous limestones overlain by shale. If the two series are placed side by side, their mutual resemblance becomes apparent:

<i>Kampa dzong.</i>	<i>Phari.</i>
Spiti shales	? ?
Shale and quartzite	Shale and quartzite.
Lungma limestone	Upper limestone.
Slate, quartzite and conglomerate	Slate and quartzite.
Crinoid limestone	Crinoid limestone.
	Slate and quartzite.
	Brachiopod limestone.

Combination of the two series gives the following sequence:

Upper and partly	{	Spiti shales.
middle Jurassic.	{	Shale and quartzite.
Inferior Oolite	.	Lungma limestone.
	{	Slate, quartzite and conglomerate.
Lias	{	Crinoid limestone.
	{	Slate and quartzite.
	{	Brachiopod limestone.

This, however, is based on such imperfect data that it can be regarded merely as a suggestion for a temporary working hypothesis.

CHAPTER V.

THE JURASSIC SYSTEM (*continued*).

(e) Between Tüna and Karo La.

In spite of the great extent of the Jurassic system between the Himálaya and Lhasa, very little information beyond that gathered in the Kampa dzong and Phari areas was obtained during the march

from Tūna to Lhasa. The whole of the intervening area appears to be covered by slate, quartzite (rarely shale and sandstone) and limestone, thrown into an endless succession of complicated folds and pierced by dykes of basic igneous rock and intrusive masses of granite. The consequent destruction of most of the fossils adds to the difficulty of classifying the series, but on account of the persistence of the lithological types and the occasional presence of Jurassic fossils, the whole series is referred to that system.

The localities at which fossils were found are—

1. 2½ miles north of Dochen.
2. Tsalu.
3. Hills east of Mangtsa.
4. Khangma.
5. Hill east of Gyantse.
6. Gorchi and Salagang.

1. The first of these localities is at the top of a pass leading from Dochen to grazing-grounds between that village and Kala Tso. The fossils occur in a narrow calcareous band in dark shales and consist of *Gryphæa* sp. very badly preserved.

2. An impression of an ammonite was found in the shale at Tsalu by Mr. L. Truninger, C.I.E., but was not determinable.

3. On the hills to the east of Mangtsa, a few poorly preserved brachiopods were collected from shaly beds by Captain H. M. Cowie, R.E. They include species of *Spiriferina* sp. and the impressions of a brachiopod externally resembling the liassic species *Terebratula* (*Megerlea*) *Perrieri* Desl.

4. On the left bank of the river opposite the village of Khangma there is a cliff section of intensely folded shale and limestone. At some little distance from the river bank the base of the section is formed by a white crinoid limestone, composed almost entirely of stems of crinoids: above this

are dark calcareous shales also containing crinoids¹: near the top of the shale a few impressions of ammonites were noticed. The shale is overlain by massive limestone, apparently unfossiliferous.

None of the above fossils are determinable, and their horizon is consequently unknown; the crinoid limestone is very like that at Agang in the Phari plain (*supra* p. 26) and probably represents the same horizon.

5. Between Khangma and Gyantse the sedimentary rocks are disturbed and altered by the intrusive granite of Dzamtrang (more familiarly known to members of the late expedition as "Red Idol gorge"), and by many dykes of diabase. The latter are particularly numerous in the immediate neighbourhood of Gyantse, whilst a thin bed of amygdaloidal trap was also found interbedded with the slate in the hills to the NE. of the town. The shaly and calcareous beds have thus been altered into phyllite and calc-schist. This metamorphism has been accompanied by intense folding (see Pl. 11, fig. 1), and the absence of determinable fossils is only what might be expected. Among the hills to the east of Gyantse, metamorphism is less marked, and some imperfect fossils were found near the top of the 15,480 feet peak at about 6 miles to E.-SE. of Gyantse, in comparatively unaltered beds of shale and sandstone, which are separated by a fault from the calc-schists of the plain. The fossils include a fragment of a large specimen of *Perisphinctes* sp. and some badly preserved brachiopods and lamellibranchs. "Fucoid" remains were also found on the high ridge to the N.-NE. of the town.

From Gyantse on towards Shigatse the Jurassic slates and quartzites extend up to and beyond Penang dzong: they are full of basic intrusions, including diabase at Drongtse and serpentine at Nupuchöndzö, a small village on the left bank of the river, about 8 miles above Penang dzong.

¹ I am indebted to Captain R. Lloyd, I.M.S., for drawing my attention to the fossils in the shale.

6. The hills between Gyantse and the Karo La appear to be composed entirely of Jurassic rocks, chiefly dark shale with some limestone, striking E.-W. and dipping mainly to the north. The shales are often concretionary and comparatively little affected by the regional metamorphism so conspicuous in the neighbourhood of Gyantse, and even the occasional intrusive masses of diabase show no far-reaching contact effects, the zones of alteration being confined to the immediate neighbourhood of the igneous rock. It is quite probable therefore that, under conditions more favourable to geological work, several fossiliferous localities might be found among the hills between the Ralung Chu and the Yung La.

In the valley of the Ralung Chu fossils occur in the shales between the villages of Gupshi and Lungma.¹ They are especially numerous at Gorchi where large numbers of belemnites were collected from a band of soft shales. A few miles higher up the valley belemnites and brachiopods (*Rhynchonella* sp.) were found in the shale at Salagang, and it is probable that the hills on either side of the Nyiru Chu between Gupshi and Khangma would also prove fossiliferous for the rocks here appear to be less altered than their more westerly representatives in the upper reaches of the Nyang Chu.

(f) **Between Karo La and Nam Tso.**

In the neighbourhood of the Karo La metamorphism is again prevalent and the rocks at the mouth of the gorge leading up to the pass are schistose limestones (calc-schists) overlain by slates, which latter form the snowy peak of Nöjinkangsang—the most conspicuous land-mark between Bhutan and Lhasa—and the greater part of the neighbouring ranges. The metamorphic character of these rocks is due chiefly to the presence of intrusive granite, which occurs in the hills to the north of Nöjinkangsang, and which, though not seen *in situ*, is represented by numerous boulders in the valleys to the east of the Karo La.

¹ Not to be confused with the grazing-ground of the same name near Kampa dzong.

Thence on to Nangkartse, throughout the hills surrounding Yamdrok Tso, and again along the valleys of the Brahmaputra and the Kyi Chu, metamorphism is practically universal, due first to the many diabase intrusions around the shores of the lake and subsequently further north, to granite.

In the immediate neighbourhood of Lhasa granite is the prevailing rock and the local sedimentary beds are highly metamorphosed but Jurassic rocks still predominate in the surrounding hills and appear to continue far to the north towards Nam Tso. From the summit of the Pempogo La can be seen an endless succession of shale and quartzite, striking E.-W. and extending across the Pempo valley into the ranges to the south of Nam Tso. The apparent regularity of the bedding points to comparative absence of disturbance among the rocks of these ranges and since Cretaceous fossils (*Omphalia trotteri* Fstm.) were found by Pandit Nain Singh in the neighbourhood of the lake,¹ it is probable that an expedition across this belt of country would be productive of valuable stratigraphical results.

CHAPTER VI.

THE KAMPA SYSTEM (CRETACEOUS AND TERTIARY).

A more striking contrast than that between the Jurassic and overlying systems of southern Tibet it is difficult to conceive. The former is of enormous extent, is composed chiefly of arenaceous and argillaceous beds and is, with one rare exception, sparsely fossiliferous, while the latter is of very small extent, consists chiefly of calcareous rocks and contains a large and varied, if not well-preserved, fauna.

These younger beds are especially well exposed in the neighbourhood of Kampa dzong, where they form the conspicuous range of hills standing out in the middle of the plain (see p. 31); they may therefore be appropriately named the Kampa system. Although the

¹ *Rec. Geol. Surv. Ind.*, X, p. 21.

superficial extent of this series is small, it is probably less so than would be supposed from the map, for it is quite possible that it may occur among the hills between the Nyang Chu and the Yaru plain, and where the local rocks are highly metamorphosed, as in the country around Gyantse, some of the calc-schists mapped as Jurassic may include in-folded patches of Cretaceous beds.

The chief exposures of the Kampa system are found along a band running from Kampa dzong to Tūna and forming
Giri limestone. a series of more or less faulted folds trending approximately E.-W. The oldest member appears to be a band of hard thin-bedded limestone which dips to the north and forms a small ridge at about 7 miles to the E.S.E. of Kampa dzong and a short distance from the southern flanks of the Kampa-Tatsang range. No fossils were found in the limestone, which, however, immediately overlies the Spiti shales and is therefore probably of lower Cretaceous age. A similar series of limestones is seen again on the banks of the Giri river about 3 miles above Giri, faulted under the Spiti shales and dipping at high angles to the south (Pl. 8, fig. 1).¹ On the right (north) bank of the stream it is faulted against the Jurassic shales and sandstones.

The overlying beds consist of a series of brown shaly limestone with brown and black needle shales. Through
Kampa shales. the shales are narrow bands of concretions of very hard splintery limestone, which, between the village and the monastery at Kampa dzong contain cephalopods of the general type of *Acanthoceras rhotomagense* Defr. and appear to include

A. Newboldi Kossmat,
A. Hunteri Kossmat, and
A. laticlavium Sharpe;

in addition to these they contain specimens of *Turrilites*, including
T. costatus Lmck. and
T. cf. circumtæniatus Kossmat.

¹ For convenience of reference this band may be termed the "Giri limestone."

The same beds are found again with fossils at about 5 miles to the E. by S. of Kampa dzong along the southern slopes of the ridge running from Kampa to Tatsang. The fossils are not well preserved being frequently replaced to a large extent by crystalline silica, usually in the form of bi-pyramidal crystals of colourless or of yellow quartz. The ammonites are consequently fragmentary, but sufficient material was obtainable to establish the age of the beds as cenomanian.

The next overlying series is a band of pale grey shale about 250 feet thick. The outcrops of this horizon constitute one of the most conspicuous features of the Kampa-Tatsang range and can be seen, as a series of pale grey patches, from almost any point on the water-shed between Sikkim and the Kampa plain. Fossils are rare, but a few echinoids and lamellibranchs were found near the base of the shales on the flanks of the Kampa range, at about 7 miles E.S.E. of Kampa dzong. The echinoids are in a very perfect state of preservation and are closely allied to, if not identical with, *Hemiaster grossouvrei* Gauthier and *H. cenomanensis* Cotteau. The lamellibranchs occur chiefly in two narrow calcareous bands composed almost entirely of specimens of a small species of *Gryphæa*. The only other fossil found in any quantity in this bed, which may be named the "Hemiaster shales," is *Inoceramus* sp. of which several fragments were obtained in the neighbourhood of the *Gryphæa* bands.

The same shales are seen also on the western flanks of the Kampa ridge between Kampa dzong and Utsi, where they contain a narrow calcareous band in which are numerous badly preserved specimens of *Lithodomus* sp.

The remainder of the Cretaceous system consists chiefly of limestone which forms the greater part of the range running from Kampa dzong to Tatsang and the hills to the north and north-west of Tüna. The southern edge of the outcrop forms everywhere a well-marked scarp, in which, as a

Hemiaster shales.

Scarp limestone.

rule, three prominent bands are noticeable, separated from one another by softer shaly beds.

The most complete sections are found in the Kampa-Tatsang range, and extend from the Hemiaster shales to the highest beds of the Cretaceous system. One of the best of these is seen at the locality already mentioned, about 7 miles to the east of Kampa dzong, where most of the fossils found in the shales were obtained (see Pl. 9, fig. 1). Above the shales is a cliff of hard splintery limestone, about 150 feet high, overlain by dark shale with some thin bands of limestone, above this shale is a second limestone cliff of about the same height as the first, and above this again are gentler slopes of thin flaggy and shaly limestone sloping up to the low cliffs which form the top of the scarp; these are overlain by more shaly and flaggy limestone, lying behind the edge of the scarp and dipping under a bed of gritty, ferruginous sandstone.

A diagrammatic section is shown on Pl. 2. The first or lowest limestone is a dark splintery rock with no determinable fossils. The overlying shales, with thin bands of limestone, are also practically unfossiliferous, having yielded only a few fragments of lamellibranch shells, including a small specimen of *Gryphæa* sp.

Above the shale fossils begin to appear, and at a few feet above the base of the second limestone the rocks contain numbers of small specimens of *Orbitoides* sp.; these gradually become more and more numerous, and up to the base of the ferruginous sandstone the presence of foraminifera of this type is an almost constant feature of the limestone bands. With them is associated a large variety of fossils, including chiefly *Rudistæ*, echinoids and lamellibranchs.

The *Rudistæ* first make their appearance in the upper part of the second limestone, and this, as well as the overlying shaly limestone, is characterised by the presence of *Radiolites* sp.; with these are many echinoids, as a rule represented only by internal casts and consequently quite undeterminable.

The third and uppermost division of the scarp limestone is rather less massive than the others, being sub-divided by thin flaggy layers; it passes up into a series of thin-bedded limestone, at times highly arenaceous, with occasional sandstone bands. The sequence from the base of the third limestone up to the overlying ferruginous sandstone has been examined at various localities; a good section is seen above the right bank of the Kampa stream immediately behind the fort; others are found along the Kampa-Tatsang ridge which is capped, throughout almost its whole extent, by the ferruginous sandstone. The same series was examined again at Tüna, where it forms the lower third of the ridge behind (to the north of) the village, and is further seen on the southern slopes towards the eastern end of the same ridge; to facilitate reference these beds may be termed the Tüna limestone.

The last-named localities have furnished the following sequence (in descending order):—

	Ferruginous sandstone	
	Grey limestone, with echinoids and brachiopods	50 feet.
	Sandstone	30 "
Tüna limestone.	<i>Lithothamnion</i> limestone	} with <i>Cyclolites regularis</i> Leym., <i>Hemipneustes</i> sp. and <i>Plicatula</i> sp.
	Red arenaceous limestone	
	Grey limestone	
	Thin-bedded limestone, with <i>Vola</i> sp. and echinoids (<i>Holcotypus</i> sp.)	40 "
	Massive limestone with <i>Radiolites</i> below, <i>Actæonella</i> and <i>Gryphæa</i> (?) above	?

The lowest bed is the third scarp limestone which here, as elsewhere, is characterised by the presence of *Radiolites* sp.

Towards the upper boundary of this limestone, the *Rudistæ* disappear and are replaced by one or more species of *Actæonella*, the spiral (transverse) sections of which are very conspicuous and form a characteristic and easily recognised horizon both at Tüna and around Kampa dzong (see Pl. 13, fig. 1). It is almost impossible to extract specimens from the matrix and consequently the species could not be satisfactorily determined but is probably allied to *A. crassa* d'Orb.

Above the *Actæonella* horizon, the limestone contains equally conspicuous remains of a large *Gryphæa* or *Ostrea*,
Horizon of (?) *Gryphæa*
vesicularis. probably *G. vesicularis* Lmk.; with this are associated *Orbitoides* in gradually increasing numbers, and the overlying beds are composed almost entirely of these foraminifera. Echinoids also occur throughout this limestone, but are, as a rule, too badly preserved for determination.

The third massive limestone is overlain by a series of soft, thin-bedded limestones, containing echinoids and
Horizon of *Vola quadricostata*
lamellibranchs, the latter represented chiefly by *Vola quadricostata* Sow. The echinoids are usually casts, composed of white crystalline calcite with little or no trace of test; they appear, however, to include the genera *Holæctypus*, *Echinanthus* and *Pyrina*.

Above this is a band of brown limestone, containing fragments of small brachiopods and large numbers of foraminifera, chiefly *Orbitoides* sp. and *Orbitolites*
Horizon of *Orbitolites*
macropora. *macropora* Defr.

This is overlain by a series having very well-marked characters and readily recognised in all sections. It consists of thin-bedded limestone, first grey then reddish and arenaceous, passing up into a thin band—only a few inches in thickness—of limestone containing immense numbers of calcareous algæ. Certain bands of the rock are composed almost entirely of large spheroidal nullipores, apparently belonging to the genus *Lithothamnion* (see Pl. 13, fig. 2); the other fossils include echinoids, lamellibranchs, corals and bryozoa, of which the following forms have been recognised—*Hemipneustes* sp., *Plicatula* sp.,¹ *Cyclolites regularis* Leym., *Caprina* sp.

¹ This fossil was, in the preliminary note published in *Records, G. S. I.*, XXXII, pt. 2, referred to as *Hinnites* (?) *foliaceus* Noetl. Subsequent examination of a larger number of specimens shows that it should probably be referred to the genus *Plicatula*; more than one species appear to be present, one of which is probably identical with Noetling's *Hinnites* (?) *foliaceus* from the maestrichtien of Baluchistan; another may be *Pl. hirsuta* Coquand.

In addition to these a species of *Lithodomus*, apparently identical with *L. (Modiola) deshayesii* Dixon, from the calcaire grossier of the Paris basin, occurs in considerable quantity in the Lithothamnion limestone. The species of *Plicatula* occur in the reddish arenaceous limestone and *Cyclolites regularis* together with *Caprina* sp. and other lamellibranchs in the overlying band. The former genus was found wherever a section of the uppermost Cretaceous rocks was examined; it is particularly common in the locality, shown on Pl. 9, which lies at about seven miles to E.S.E. of Kampa dzong.

The overlying sandstone and grey limestone, which intervene between the coral limestone and ferruginous sandstone are poor in fossils; the few which were found in the grey limestone consist of echinoids and traces of brachiopods, none of which were even generically determinable.

The whole of the above series from the Hemiaster shales to the ferruginous sandstone is seen throughout the Kampa-Tatsang ridge and again in the hills to the W.N.W. of Tüna, but at the latter village only the uppermost beds are exposed. In the immediate neighbourhood of Kampa dzong the beds overlying the third limestone are frequently hidden by talus derived from the ferruginous sandstone, and they were examined in greater detail at Tüna, where, however, the fossils are unfortunately in a very poor state of preservation.

To the north and north-west of Tüna, Cretaceous and Tertiary beds extend for probably ten or twelve miles, but unfortunately no detailed examination could be made of that area. A reconnaissance to the valley of the Guru river, at some miles above Guru, showed, however, that good sections were to be found in the hills to the west of that village. In the range to the south of the river the limestones with *Rudistæ* are well exposed and contain many fossils, while the higher peaks to the north of the river appeared to afford sections of both the Cretaceous and Tertiary systems, of which the latter may very possibly include beds younger than any found either at Tüna or at Kampa dzong.

Although the upper and lower limits of the Cretaceous system of Central Tibet can be approximately determined, it is at present impossible, owing to the absence of fossils from the beds both at the top and at the base, to define its exact boundaries. Nor is it possible to attempt to identify the sub-divisional units recognised in the Cretaceous of Europe. When the specimens collected at Kampa dzong and at Tüna have been worked out in detail, many of the European zones will no doubt be recognised, but it is not likely that the clearly defined stages of Europe will be represented by equally well-marked sub-divisions in Tibet, for, as in the Triassic sequence of the Himálaya, hard lines of division between two consecutive stages in all probability do not exist and the exact beginning or end of any particular stage cannot be determined.

The oldest Cretaceous fossils found either at Kampa dzong or at Tüna are those occurring in the brown shales with
Kampa shales : neocomian to cenomanian.
calcareous concretions (Kampa shales) and consist, as stated above, of ammonites of the group of *Acanthoceras rhotomagense* Deufr. with *Turrilites costatus* Lmk. These are found in the cenomanian stage in Europe, hence the whole of the lower Cretaceous (neocomian to aptian) as well as the albian stage of the upper Cretaceous must be represented by the beds lying between the Spiti shales and the *rhotomagense* horizon. These include the dark limestones seen on the bank of the Giri Chu and again at about seven miles to E.S.E. of Kampa dzong, with the overlying brown shales and shaly limestone.

The next fossiliferous horizon is that near the base of the grey shales, with *Hemiaster Grossouvrei* Gauthier,
Hemiaster cenomanian.
shales : *Gryphæa* sp. and *Inoceramus* sp., which is also presumably of cenomanian age.

From the beds between this horizon and the second scarp limestone no determinable fossils have been obtained, but
Turonian.
it is evident that the upper part of the *Hemiaster* shales, the first scarp limestone and the overlying shales must contain the turonian stage and possibly part of the cenomanian.

From the base of the second limestone upwards fossils are fairly numerous, and when the collections made have been worked out it will no doubt be possible to recognise at least some of the European horizons, and perhaps even to define their approximate limits. At present, however, the *Rudistæ* of the second limestone have not been determined and may be either turonian or senonian species—possibly both stages are represented.

The age of the third limestone appears to be at any rate partly senonian, since it is overlain by beds with typical maestrichtian fossils, such as *Plicatula hirsuta* Coq., *Cyclolites regularis* Leym., *Orbitolites macropora* Defr. and species of *Hemipneustes*, all of which forcibly recall the maestrichtian beds of Baluchistan (see *Pal. Ind.*, ser. XVI, Vol. I, pt. 3).

The absence of determinable fossils from the ferruginous sandstone and the beds immediately below it make it impossible to define the upper boundary of the Cretaceous system, but it seems hardly likely to lie below the base of the sandstone and may possibly be above it: there is no sign of the unconformity which is so frequently found at the base of the Tertiary system in India.

The only area not yet referred to, in which rocks believed to be of Cretaceous age were seen is the immediate neighbourhood of Lhasa. The prevailing rock on the right side of the Kyi Chu from Lhasa to Trölung is granite, but along the lower slopes of the hills there are dark shales overlain by limestone. On the spur running out into the Lhasa plain beside Nechung, the temple of the Oracle, a series of limestone and slate dips into the hill against the granite of the main ridge; all the beds are much altered by the granite, but traces of fossils, apparently including echinoids, were seen in the limestone.

For several miles below Drepung the lower spurs are composed chiefly of limestone, and near Gang-gi-ri, where a gigantic figure of Buddha has been carved on the face of a limestone cliff, some of the beds are distinctly fossiliferous. Unfortunately the fossils are merely represented by sections of what appear to be lamellibranchs and in some cases resemble sections of *Radiolites*, but neither here nor on the

Nechung spur were determinable specimens found. This band is overlain by quartzite—a combination suggesting the upper Cretaceous series and ferruginous sandstone of Tüna and Kampa dzong. Further down the Kyi Chu valley and also up the Trölung Chu, these beds are apparently underlain by shale and slate, part of the extensive series which has been referred to the Jurassic system.

The same limestones occur again between Lhasa and the Pempogo La and run on through the higher ridges bordering the Lhasa plain. Just below the Pempogo La they are underlain by the typical Jurassic beds of central Tibet, and in spite of the want of palæontological evidence, it is difficult to resist the conviction that this calcareous series, overlain by quartzite, is the equivalent of the Cretaceous system of Tüna and Kampa dzong and probably connected with beds of similar age known to occur at Nam Tso.¹

Throughout the rest of the area visited Cretaceous beds are apparently absent, though, as already stated, they may occur among the metamorphosed rocks between Gyantse and Kampa dzong. The extent of the system at Nam Tso is quite unknown.

CHAPTER VII.

THE KAMPA SYSTEM—(*continued*).

On every section on which it has been found, the uppermost Cretaceous (Tüna) limestone is invariably overlain by a bed—about 200 feet thick—of coarse sandstone, gritty and slightly conglomeratic in parts and frequently highly ferruginous. In the hills around Kampa dzong, it contains small segregated masses of iron ore, usually one of the hydrated forms, but occasionally pure hæmatite. The change from

Ferruginous sandstone.

¹ *Supra* p. 40.

the underlying rocks to this sandstone is never particularly abrupt, for the limestones above the horizon of *Orbitolites macropora* are always more or less arenaceous, and in some instances contain bands of true sandstone. Although comparatively rapid, the change to shallow-water conditions must have, at least in the Tüna-Kampa dzong area, been gradual and there is no sign of unconformity. The absence of fossils in the sandstone combined with the absence of any marked stratigraphical break in the sequence thus makes it impossible to demarcate the boundary between Cretaceous and Tertiary, and the sandstone may belong to either one or the other, or indeed partly to both. In the preliminary note published in *Records, G. S. I.*, Vol. XXXII, pt. 2, it was provisionally referred to the danian stage,¹ but the ambiguity connected with that term renders its use undesirable, while the interval between maestrichtian and eocene may possibly be entirely represented by the eighty feet or so of limestone and sandstone above the Lithothamnion limestone.

The ferruginous sandstone is succeeded by a series of calcareous beds which are lithologically not unlike the **Gastropod limestone.** underlying Scarp limestone, but at their base there is a more decidedly abrupt change from sandstone to limestone than has been observed at any part of the underlying beds. The sandstone passes rapidly up into limestone which is at first thin-bedded but is subsequently a hard dark massive rock full of badly preserved casts of gastropods; above this is a shaly foraminiferal limestone, which passes up into shale overlain by more massive limestone with *Orbitolites*. The whole of this series, together with some shale and flaggy sandstone which overlies the *Orbitolites* limestone, appears to be of Tertiary age.

The only section that was examined in detail occurs in the hills behind Kampa dzong²: it is perhaps best seen in the gorge at about

¹ p. 165.

² A more complete section would probably be found at the Dzongbuk La (see below p. 56).

2½ miles above the village, where the sequence is as follows (see Pl. 10) :

Sandy and micaceous shale, with flaggy sandstone, and a narrow calcareous band near the base ;

- (4) Orbitolites limestone ;
- (3) Shale, variously coloured, ranging from black to greyish, with " needle-shales " (" Spondylus shales ") ;
- (2) Soft shaly and nodular limestone, full of foraminifera (" Operculina limestone ") ;
- (1) Hard, dark, massive limestone, thin-bedded at base (" Gastropod limestone ") ;

Ferruginous sandstone.

With the exception of the ferruginous sandstone, each of the above horizons is more or less fossiliferous ; but the lowest limestone (1) is cut through by the stream and that part of the section is much obscured. The lower beds, however, are almost invariably found capping both the ridges which run from Kampa dzong to Tatsang ; on the more southerly of the two they are in normal sequence above the Scarp limestone, but on the northern ridge they have been thrown above younger beds by an important strike-fault, which extends certainly for 20 miles from east to west and probably persists for a very much greater distance ; although almost coincident with the strike, it appears to draw slightly away from it towards the east, and to run rather more to the north of east.

In the neighbourhood of Tüna exactly similar sections of the lower part of the Tertiary system are seen throughout the ridges between that village and Guru, but only the ferruginous sandstone, the lowest limestone and the shaly foraminiferal limestone occur on the Tüna ridge. Younger beds would almost certainly be found in the higher hills to the west of Guru, but unfortunately these could not be visited. The Tüna sections, however, have proved of considerable value, for they have furnished fossils from the beds immediately above the ferruginous sandstone, and have considerably supplemented the collections from the massive limestone of Kampa

dzong. A part of the southern side of the ridge is shown on Pl. 12, fig. 2, on which (1) represents the ferruginous sandstone and (2) the massive limestone. The ferruginous sandstone is the lowest bed seen on the section, and to the east—right-hand side of the picture—it is almost entirely cut out by a fault, which brings the limestone down on to the upper Cretaceous beds (see also Pl. 4). Between the sandstone outcrop and the base of the limestone cliff, most of the slope is covered with débris, but sandstone can be seen here and there at intervals for the greater part of the distance; higher up it is replaced by thin-bedded limestone, which begins a short distance below the foot of the cliff. At the point marked \times occurs the first fossiliferous horizon found above the sandstone; this is a narrow band of pale grey limestone full of foraminifera, which to the naked eye appear to be entirely *Orbitolites* sp. Under the microscope, however, the matrix is found to be largely made up of smaller foraminifera, chiefly members of the family *Miliolidæ*. At about twenty feet above this a section just to the east of that shown on Pl. 12 yielded a few badly preserved gastropods and a *Nautilus*. Above this scattered fossils occur throughout the limestone; they are chiefly gastropods, with some echinoids and lamellibranchs, in almost all cases badly preserved internal casts with no trace of shell. The total thickness of this limestone is difficult to estimate, owing to the universal faulting; both at Tüna and at Kampa dzong it appears to be about 300 feet. In the sections on the ridge immediately behind Kampa dzong, a band of shale, about 40 feet thick, occurs rather above the middle of the limestone; it is not so conspicuous at Tüna, although a certain amount of shale is seen there also; no fossils were found in it at either locality.

The whole of this limestone series, which may be conveniently termed the "Gastropod limestone," appears to belong to one horizon. With the exception of the foraminifera, which are more conspicuous in the lower beds, the same fossils seem to occur throughout. Gastropods largely predominate and include several genera of which the commonest are *Ovula*, *Cerithium*, *Phasianella*, *Fusus*, *Voluta*, *Conus*

and *Velates*. The last-named genus occurs in considerable profusion in the upper part of the limestone, and extends into the overlying shaly foraminiferal limestone; at Tüna, however, it was found also in the lower beds with *Nautilus* sp. cf. *sublævigatus* d'Orb. The commonest—possibly the only—species is *Velates schmideliana* Chemn.,¹ which determines the age of the limestone as eocene. In addition to the above fossils, part of a claw of a crab was found at the top of the limestone on the ridge behind Tüna.

The gastropod limestone is overlain by a shaly nodular limestone containing large numbers of foraminifera, chiefly *Operculina* limestone. *Operculina* and other *Nummulinidæ*. In the neighbourhood of Kampa dzong this rock is usually found capping the ridge to the north of the village, and it occupies a similar position on the ridge to the north-west of Tüna (see Plates 8, fig. 1, and 12, fig. 2). When found in this position it usually resembles a nodular calcareous shale rather than a limestone, for, owing to its soft and shaly character, it readily succumbs to the violent disintegrating forces at work in the extreme climate of Tibet. In less exposed sections, however, it appears more compact, and in the Kampa gorge at about half a mile above the fort it forms steep cliffs bordering the stream (see Pl. 11, fig. 2).

This rock forms a very characteristic and readily recognised horizon. It is always markedly nodular, and the nodules, being harder and more compact than the shaly interstitial matter, stand out conspicuously on the cliff face; at the same time they appear to be covered with small dark specks which on closer inspection prove to be foraminifera weathered out from the soft matrix. Few fossils other than foraminifera occur in this limestone, but gastropods and lamellibranchs were found both at Kampa dzong and Tüna and *Nautili* at Tüna. The gastropods are represented chiefly by *Velates schmideliana* Chemn., which is fairly common in the highest beds of the limestone at Kampa dzong: at least two species of *Nautilus* occur, one of which closely resembles *N. sublævigatus* d'Orb.

¹ I am indebted to my colleague, Mr. G. H. Tipper, for the determination of this species and also for much assistance in dealing with the fossils from the underlying Cretaceous beds.

The *Operculina* limestone is overlain by a bed, about 150 feet thick, of fine-grained greenish, grey and black shale, full of small nodular masses of marcasite. It is exposed on the right bank of the Kampa stream, at about one mile above the fort, where it is to some extent fossiliferous.

The fossils which are poorly preserved and still await determination, include chiefly lamellibranchs and gastropods; of the former *Spondylus* is the commonest genus, and is the predominant fossil of the shales, which may therefore be conveniently termed the "Spondylus shales;" other genera present are *Ostrea*, *Chama* and *Cardium*.

The gastropods are represented chiefly by *Velates schmideliana*, which extends up from the underlying limestone.

One echinoid (? *Cyphosoma* sp.)¹ was found, but is too fragmentary to admit of specific determination.

Foraminifera, apparently similar to those of the *Operculina* limestone, are found in calcareous bands in the shale.

The *Spondylus* shales are overlain by a limestone band about 50 feet thick, the lower layers of which are argillaceous and contain large specimens of *Orbitolites* sp. Higher up the limestone has yielded also *Alveolina*. Under the microscope the rock is found to be composed largely of *Orbitolites* sp. with *Alveolina* and *Miliolina* (*Quinqueloculina*).

Above this limestone is a bed of sandy micaceous shale with thin sandstone flags. The maximum thickness seen is about 150 feet. Here the upper beds end, being cut off abruptly by an important strike fault which throws them beneath older Tertiary horizons (see Pl. 3, fig. 2). The shales are to some extent fossiliferous, containing lamellibranchs (*Solen* sp.) in the lower layers and lamellibranchs and gastropods in a calcareous band about 80 feet above the base.

The description of the above sequence, from the *Operculina*

¹ I am indebted for this determination to my colleague, Mr. E. Vredenburg.

limestone to the top of the sandy shale is based on the section exposed on the right bank of the Kampa gorge at about one mile above the fort. This is shown on Pl. 10.

The beds on the ridge on the north side of the stream are very much disturbed, the line of junction between the youngest Tertiary shale and the overlying Operculina limestone being a fault. Numerous other faults occur both along and across the strike of the beds; a prominent fault of the latter type is shown on Pl. 12, fig. 1.

This fault, which is exactly followed by the path over the ridge has resulted in very considerable horizontal displacement, and has brought the Operculina limestone, on the east of the fault, into line with the upper part of the Cretaceous limestone (Vola horizon) on the west.

All this disturbance has greatly complicated the sections throughout the ridge; on the hills to the north of the Dzongbuk La, the watershed between the Kampa and Tatsang streams, the beds appear to have been inverted, for the ferruginous sandstone is found underlying the third scarp limestone. This locality is one of considerable interest, for at the point where the road ascends to the Dzongbuk La an outcrop of *Alveolina* limestone was found dipping at a high angle to the north, under dark shales which were at first assumed to represent the beds above the Orbitolites limestone in the section already described. The Dzongbuk limestone, however,

Alveolina limestone. differs from that seen nearer Kampa dzong in being composed almost entirely of *Alveolina*. It was at first mistaken for nummulitic limestone¹ and the error was only discovered when a thin slice of the rock was put under the microscope.

Unfortunately this section is complicated by disturbance as well as obscured by débris, and being, under the circumstances prevailing at the time it was visited, very difficult of access, it was not examined

¹ See *Rec. Geol. Surv. Ind.*, Vol. XXXII, pp. 165 and 171, where the rock is erroneously called nummulitic limestone.

in detail; this is to be regretted since the relation of the *Alveolina* limestone to the underlying beds has not been ascertained, but the probable stratigraphical conditions are shown in the section on Pl. 3, fig. 3.

The *Alveolina* limestone crops out on the Dzongbuk La, in the gap between the two ridges of the Kampa-Tatsang range; it is overlain by a considerable thickness of dark shale, which forms the lower slope of the northern ridge; this is overlain by limestone followed by sandstone, the line of junction being apparently the continuation of the fault referred to above (p. 49). The ridge is capped by limestone with *Radiolites* and it appears therefore that the beds lie in a reversed fold (see Pl. 3, fig. 3).

The *Alveolina* limestone is underlain by a series of shale and limestone, but this part of the section was not examined in detail and part of it is doubtful; the beds on the upper part of the southern ridge are the upper Cretaceous (maastrichtian) limestone and the ferruginous sandstone. It is probable therefore that the doubtful part of the section includes the lower part of the Tertiary system as described above from the section close to Kampa dzong and the shales which underlie the *Alveolina* limestone probably represent the sandy and micaceous beds above the *Orbitolites* limestone. The *Alveolina* limestone and the overlying shales would in that case be younger than any beds seen on the section previously described.

A curious feature of this series of Tertiary beds is the apparent absence of nummulites, which have not been recognised among the many foraminifera found in almost every horizon from the base of the Gastropod limestone to the top of the Dzongbuk shales.¹ The total thickness of the beds enclosed between these limits must be almost, if not quite, 1,000 feet, and there can be no doubt that they all belong to the eocene series, whilst the absence of nummulitic limestone may possibly be due to the fact that that stage had not yet been

¹ This name may be temporarily given to the shales which overlie the *Alveolina* limestone on the Dzongbuk La.

reached and that in the Tertiary system of southern Tibet we have a series analogous to the older Tertiaries—the lower Ranikot—of western Sind.

CHAPTER VIII.

IGNEOUS ROCKS.

Both acid and basic igneous rocks are fairly numerous throughout the area visited by the mission. The former consist chiefly of granite and the latter of an extensive series of basic dyke-rocks, including diorite, augite-norite, epidiorite and serpentine. In addition to these a number of pebbles of volcanic rocks allied to dacite were found in the gravels of the Tsangpo between Kampa-partsi and Chaksam; these were not found *in situ* but most probably occur in the Tsangpo valley between Kampa-partsi and Shigatse.

In the valley of the Nyang Chu basic intrusions are numerous and have been noticed at various points in the hills on either side of the river. To the south of Gyantse several dykes are seen cutting through the Jurassic slates; one of these forms a ridge at about seven miles to the south-south-west of the town and consists of much decomposed lath-shaped plagioclase, with large quantities of chlorite, ilmenite, leucoxene and apatite. The most striking feature of this rock is the great abundance of the apatite, the freshness of which contrasts strongly with the advanced state of alteration of all the other constituents.

At Tsechen and again at Drongtse, there is a coarser greyish-green rock, composed of plagioclase,—almost completely replaced by saussuritic decomposition products—with chlorite, some quartz, ilmenite, much leucoxene, and a little calcite and actinolite: this rock appears to have been originally a diorite, and probably marks a stage of decomposition rather more advanced than that of the basic intrusions at Gupshi, at the junction of the Ralung and Nyiru rivers. This latter rock, although much altered, is still recognisable as

an ophitic augite-norite and is very similar to other dyke-rocks found between Hring La and Nangkartse and along the shores of Yamdrok Tso. There is nothing sufficiently remarkable about the rock to warrant a detailed description : it is composed of plagioclase, probably labradorite but much decomposed, augite and enstatite both markedly ophitic, chlorite serpentine, probably derived from the decomposition of the pyroxenes, ilmenite, leucoxene and sphene.

At the village of Nupuchöndzö between Drongtse and Penang there is a very conspicuous intrusion of serpentine with large lustrous phenocrysts of bastite. It has been considerably crushed and the black and shining slickensided surfaces give it a superficial resemblance to coal, which probably accounts for the persistent rumours regarding the occurrence of that mineral between Gyantse and Shigatse.

All the above rocks are found intrusive in the Jurassic slates, but a dyke of similar character was also noticed among the limestones, regarded as of Cretaceous age, between Trölung and Nyetang in the valley of the Kyi Chu. They are therefore not older than upper Cretaceous and may be younger, possibly contemporaneous with the basic intrusions which are found in the Tertiary volcanic series of Ladak² and in the Palæozoic beds of Spiti and Rupshu, and it further seems reasonable to unite these occurrences of basic igneous rocks, as well as the dacites of the Tsangpo gravels, with the volcanic series of Malla Johar in Kumaon⁴ and the neighbourhood of Manasarowar and Rakas Tal⁵ and to regard them all as Tertiary (later eocene) in age.

The most constant feature of the rocks described above is their

¹ Fragments of similar basic rocks related to diabase and epidiorite were also found in the Kampa dzong and Phari areas ; they were not seen *in situ* but are presumably intrusive in the Jurassic slates.

² Petrological notes on some Peridotites, etc., from Ladakh ; by Lt.-Genl. C. A. McMahon, F.R.S., *Mem. Geol. Surv. Ind.*, XXXI, pt. 3.

³ H. H. Hayden : *Mem. Geol. Surv. Ind.*, XXXVI, pt. 1, 98.

⁴ A. von Krafft : *Mem. Geol. Surv. Ind.*, XXXII, pt. 3.

⁵ R. Strachey : *Journ., R. Geol. Surv. Soc.*, XXI, 1851 (68) ; *Q. J. G. S.*, VII (1851), 308.

advanced state of alteration, as evidenced by the presence of secondary minerals such as epidote, leucoxene, calcite and serpentine, and in this respect they present a striking contrast to a mass of basic rock, not yet referred to, which is intrusive in the Jurassic slates of the Tsangpo valley. This rock forms a high and conspicuous hill on the right bank of the river at Chaksam and is essentially a coarse-grained hornblende-diorite. Under the microscope, it is found to be composed of plagioclase felspar, partly oligoclase and partly a more basic variety approaching labradorite, with some orthoclase and large quantities of a brownish-green hornblende occasionally showing idiomorphic outlines. There are also a few irregular patches of hornblende containing a colourless mineral with high refractive index and high double refraction, possibly pyroxene which has been partially altered to secondary hornblende. In addition to these, there is a considerable quantity of biotite, chlorite and magnetite and a little sphene; the chlorite has probably been derived from the alteration of hornblende and biotite. Quartz is present, but in very small quantity. The felspar is often beautifully zoned and, as a rule, fresh and little altered, in this respect differing very markedly from the saussuritized felspars of the diabases: indeed, with the exception of the chlorite and the small amount of (?) secondary hornblende, the rock is almost free from alteration. It is associated with and probably genetically related to the granite of the Kyi Chu valley,

Kyi Chu granite.

which is found on the opposite bank of the Tsangpo and runs thence in a broad band along the valley of the former river up to and beyond Lhasa. The relationship of the two rocks is further borne out by the character of the granite, which differs markedly from both the typical foliated biotite-granite and the muscovite-schörl-granite of the Himálayan crystalline zone. The latter varieties as seen in Sikkim and Chumbi differ in no respect from the similar granites of the more westerly parts of the Himalaya, and in the upper reaches of the Lachen river resemble those of the Sutlej valley in having beryl as one of the constituents of the pegmatite.

The Kyi Chu rock, on the other hand, is essentially a hornblende-albite-granite, and is composed of quartz, orthoclase, albite, microcline, perthite, oligoclase, hornblende, biotite, apatite, epidote, sphene and magnetite. The plagioclase is very abundant, hornblende and biotite are always present in considerable quantities, while the sphene is a conspicuous and almost essential constituent of the rock. In the neighbourhood of Lhasa there are two varieties of the granite, a coarse-grained form with much quartz and having a specific gravity of 2.65, and a fine-grained, less acid type, in which sphene and the ferro-magnesian minerals are very conspicuous and raise the specific gravity to 2.70. This rock differs in several points from the acid variety. It is especially characterised by the presence of various lime-bearing minerals including sphene, epidote and calcite, of which the first two are particularly conspicuous both in the hand-specimen and under the microscope. The presence of such a marked calcareous element in the granite amounting to nearly 4.7 per cent. of CaO is at first sight surprising, since the basic felspar is neither large enough in quantity nor far enough advanced towards alteration to have yielded an appreciable amount of epidote and calcite. Nor apparently have either of these minerals arisen from the decomposition of the hornblende; this may have occurred in certain instances, where the calcite and epidote are found in association with hornblende, but in other cases they are associated neither with hornblende nor with plagioclase, but appear to have crystallised out independently among pre-existing individuals of quartz and orthoclase; thus in the case shown on Pl. 14, fig. 4, the calcite is found surrounding and enclosing fragments of a single crystal of orthoclase, the various parts of each mineral being, respectively, in optical continuity; the epidote also shows a similar habit. At the same time the epidote and calcite frequently occur in association with one another and with the sphene, and all three appear to have arisen at one and the same stage in the life-history of the rock. A simple explanation of their origin seems to lie in the absorption, by the granite, of lime from the rocks into which it has

been intruded. In the Kyi Chu valley, as at Gyantse and elsewhere the slates are not infrequently calcareous and contain bands of limestone and calc-schist, and the absorption of these by the granite, at a stage prior to its complete solidification, would result in the production of such minerals as sphene and epidote, the excess of lime combining with carbonic acid to form calcite.

A very handsome porphyritic granite, with large phenocrysts of flesh-coloured orthoclase, occurs on the right bank of the Kyi Chu at Nam, about 23 miles below Lhasa.

Basic *schlieren*, probably representing fragments of the sedimentary rocks into which the granite has been intruded, and composed of idiomorphic crystals of felspar and ragged patches and rods of hornblende, frequently twinned, are very common in the granite both at Nam and also at Chushü on the left bank of the Tsangpo.

It is evident therefore that the Kyi Chu granite differs essentially from the ordinary varieties of the Himálayan rock: from the typical foliated biotite-granite, it may be distinguished by the absence of foliation and the presence of hornblende as an essential constituent and from the muscovite-schörl-granite by the presence of hornblende and the absence of tourmaline and muscovite. It is interesting to note that Professor Garwood records the presence of fragments of an unfoliated hornblende-granite among the blocks scattered over the surface of the Zemu glacier in Sikkim¹ and also of a fine-grained hornblendic gneiss in the moraines of the Kinchinjunga glacier²; he does not, however, give a detailed description of either of these rocks, but notes the absence of hornblende from the prevailing gneiss of the Kinchinjunga area and suggests that the hornblendic variety may belong to a different rock into which the former has been intruded. He states also that intrusive veins of hornblende granite occur in the gneiss at Jongri³; the same rock apparently, was noticed by Mr. Bose.⁴

¹ D. W. Freshfield: *Round Kangchenjunga*. Appendix by Prof. E. J. Garwood, 285.

² l. c. p. 289.

³ l. c. p. 290.

⁴ *Rec. Geol. Surv. Ind.*, XXIV, 51.

There would thus appear to be three series of igneous rocks in Central Tibet, *viz.*, (*a*) the foliated biotite granite of the Himálaya, with its associated schorl granite, (*b*) a series of basic dykes chiefly diabase and serpentine, and (*c*) the hornblende-sphene granite and associated hornblende-diorite, of the Tsangpo and Kyi Chu valleys.

The first of these series is undoubtedly merely a continuation of the great granitic axis of the Himálaya; it is intrusive certainly into beds of Jurassic age, and to the north-east of Chomolhari, in the neighbourhood of the Lingshi La, will most probably be found to have affected the Cretaceous and Tertiary beds of the Kampa series, in which case it could not be older than eocene. This has not been definitely ascertained, but unless the Lingshi range proves to be an original limit of deposition—a rather improbable supposition—it is impossible to avoid the conclusion that the Kampa series is represented among the metamorphosed sediments in the peaks to the north of the Lingshi La. This particular area has not been visited, but its importance is apparent since, should the Kampa series be found there, it will furnish the first positive evidence of the Tertiary age of the Himálayan granite.

Since the basic volcanic series of Ladak and Kumaon¹ are regarded as of eocene age, the dykes found intrusive in them in both areas are therefore either practically contemporaneous or probably younger. Similar rocks have also been found intrusive in the biotite-granite of Rupshu,² and if we are justified in assuming that the diabases and serpentines of Central Tibet are but part of the same series, they also must be younger than the biotite granite.³

There is still less direct evidence, with regard to the age of the third series, the Kyi Chu granite and associated hornblende-diorite. It

¹ R. Lydekker: *Mem. Geol. Surv. Ind.*, XXII, 111; A. von Krafft: *Mem. Geol. Surv. Ind.*, XXXII, 138.

² H. H. Hayden: *Mem. Geol. Surv. Ind.*, XXXVI, 100.

³ We are unfortunately dependent on this indirect and somewhat involved, method of argument in endeavouring to fix the age of the basic intrusive rocks of Central Tibet, since they were not observed in contact with granite in the comparatively limited area that could be visited.

has already been pointed out that it is almost certainly not older than upper Cretaceous. The mineralogical characters of the granite differ so markedly from those of the typical biotite-granite of the Himálaya, that one is at first tempted to regard the two as belonging to separate petrographical provinces, but an analysis of the difference shows that it consists almost entirely in the preponderance in the Kyi Chu rock of lime and lime-bearing silicates, which as stated above may be explained by modification of the granite by the rocks into which it was intruded.

The numerous pebbles of dacite and other volcanic rocks found in the Tsangpo gravels between Kampa-partsi and Chaksam, appear to be genetically related to the Kyi Chu granite and may very possibly be extrusive portions of the same magma. At the same time the diabases and serpentines described above may equally represent yet another phase in the process of differentiation.

Both the dacites and the diabases are remarkable for the advanced state of alteration of many of their constituents, such as the feldspars and the ferro-magnesian silicates, and are consequently rich in secondary minerals, such as epidote, chlorite, calcite, serpentine and leucoxene. In marked contrast to this is the comparative freshness of the constituents of the hornblende-diorite of Chaksam. This rock, however, as already stated, occurs in the immediate neighbourhood of the granite; it is coarse and granitoid in structure and was therefore presumably formed at a considerable depth below the surface, in what Van Hise¹ terms the "zone of anamorphism," whereas the highly altered rocks were injected as dykes—possibly even extruded as surface flows—among the higher layers of the crust, termed by the same author the "zone of katamorphism," which he regards as the seat of such secondary changes as hydration, oxidation and carbonation. The mere accident of position, or relative depth below the surface, would thus suffice to account for the varying degrees of alteration of different parts of the same magma.

¹ C. R. Van Hise : A Treatise on metamorphism, *U. S. Geol. Survey Monographs*, XLVII (1904).

The presence of serpentine among the basic rocks intrusive in the sedimentary systems of India and Burma and its almost complete absence from the dunites and other olivine-bearing rocks found in the old crystalline complex of the Indian peninsula, led Mr. Holland to the conclusion that extensive serpentinisation is probably due to submarine agencies.¹ If we apply this theory to the serpentines of Central Tibet, their age will be limited by that of the most recent marine sediments deposited in the old Tibetan sea, and as no stratified rocks of marine origin younger than eocene have yet been found, it is reasonable to assume that the age of the basic intrusives is not less than upper eocene. This is a further argument in favour of correlating these rocks with the basic dykes and eocene volcanic series of Ladak and Kumaon.

CHAPTER IX.

ECONOMIC GEOLOGY.

The area visited during the recent expedition is strikingly poor in minerals of economic value, the only one found **Gold.** *in situ* being gold, which was obtained in very small quantities from the coarse gravel beds of the Tsangpo; these were panned at various points near Chaksam, but the largest yield was only at the rate of '28 grain of gold per ton of gravel. The concentrates were found to contain, in addition to much magnetite and zircon, a small quantity of rutile, tourmaline, hercynite, and monazite (see Appendix A).

Persistent rumours of the occurrence of coal both in the Nyang **Coal.** Chu valley, near Penang, and at Lhasa proved to be groundless. In the former case it is highly probable that the supposed coal is the serpentine occurring at

¹ T. H. Holland : *Brit. Association Report* (1898), 868 : *Geol. Mag.*, Dec. IV, Vol. VI (1899), 30, 540.

Nupuchöndzö and elsewhere in the lower Nyang Chu valley. At Lhasa the prevailing rocks are granite and Jurassic slate and quartzite, with no trace of carbonaceous beds, while the fuel employed in the local "arsenal" was found to be not coal—as had been reported—but charcoal. Some quantity of graphite was found in this

Graphite.

building, being used for the manufacture of crucibles, and I am indebted to Mr. E. C. Wilton, C.M.G., Assistant to the British Commissioner, for samples of the mineral, and also for the suggestion that it represents the so-called "coal." The graphite is said to come from the Rong valley between

Lead.

Yamdruk Tso and Shigatse. The same valley is also said to yield lead, but the report was not substantiated by any reliable evidence.

Gem-stones.

While at Lhasa, I bought a number of samples of the gem-stones employed by the local jewellers; these included turquoise, ruby, tourmaline, emerald, and sapphire. The jewellers stated that all these stones were brought from considerable distances, the turquoise being obtained from Ladaki and Mongolian traders, the rubies and emeralds from India and Mongolia, and the sapphires from Ladak and India. I could obtain no reliable information as to the existence of any indigenous source of gems. The rubies and emeralds were small and very pale; the sapphires were, on the whole, of better quality, but small, often pale and flawed, and though a few stones of good colour were to be obtained, they were very small and of little value. Pink tourmaline is also apparently used largely, not being distinguished from ruby of similar colour. Yellow and white rock-crystal and red garnet are also used. It appears that, with the exception of turquoise, practically all the gem-stones used in Lhasa come from foreign countries, and it is not at all improbable that quite a large proportion of them come from Ceylon and Burma, *vid* Calcutta and Nepal.

An efflorescence, composed chiefly of sodium carbonate, is found in the valley of the Yaru river near Utsi; this is

Sodium carbonate.

collected and used by the Tibetans for various purposes, both industrial and culinary.

CHAPTER X.

SUMMARY.

1. To the north of Sikkim and Bhutan the orographic conditions

Orography.

are apparently much more complicated than in the area to the north of Nepal and Kumaon.

The northern range of the Central Himálaya no longer exists as a definite unit but merges into a series of variously oriented ranges with intervening depressions. The Tsangpo, however, occupies a continuous trough from its source to the point at which it turns to the south and cuts its way out to the plains of Assam. On the north of this trough are the Tibetan ranges, named by Trelawney Saunders the Gangri mountains, and to the south the high range of snowy peaks including Everest, Kīnchinjunga, Chomolhari and the other giants of the Himálaya. On the north of Nepal this latter range is separated from the northern range of the Central Himálaya—the water-parting between the Gangetic drainage and the Tsangpo—by an apparently continuous depression parallel to the trough of the Tsangpo. To the north of Sikkim and Bhutan, however, this depression is no longer continuous, but may be represented by a series of broad plains and lake basins, including the Yaru plain and Kala Tso.

2. Stratigraphically two broad zones have been recognised, *viz.*,

Stratigraphy.**Crystalline zone.**

the crystalline and metamorphic to the south and the Tibetan zone of fossiliferous sediments to the north. The former zone embraces the

high snowy range of the Himálaya, and is composed of granite, gneiss and a series of crystalline and metamorphic rocks, including pyroxene-scapolite granulite, graphitic sillimanite gneiss, crystalline limestone, mica schist and quartzite. These appear to represent the Archæan rocks of the Peninsula and Burma; the Dharwar system may be represented by the Daling series of Sikkim and the metamorphosed sediments of the Khongbu valley may be the crushed representatives of the Vindhya of the Plains.

3. A thick series of limestone, slate, shale and quartzite—the

Dothak Series.

Dothak series—which forms the hills to the south of the Phari plain represents a part at least of the Trias and may possibly include also older systems, but the paucity of fossils and the poor state of preservation of those found, have afforded no evidence as to the age of the lower beds, but some limestones at the top of the series contain brachiopods which are regarded as of liassic age.

4. The greater part of the provinces of Tsang and Ü is covered

Jurassic System.

by Jurassic rocks. The lower beds contain few fossils, but highly fossiliferous limestones of middle Jurassic age, with *Trigonia costata* Park. and species of *Harpoceras*, were found to the south of Kampa dzong, and fossiliferous representatives of the Spiti shales occur at Kampa dzong and in the hills to the east and south-east of Gyantse.

5. A comparatively narrow strip of Cretaceous and Tertiary rocks

**Kampa System:
Cretaceous and Tertiary.**

—the Kampa series—runs from Kampa dzong to Tüna. The Cretaceous rocks are shales, limestones, and sandstones, and represent the whole of that system. The lowest fossiliferous horizon is of cenomanian age and contains *Turrilites costatus* Lam. and *Acanthoceras rhotomagensis* Deffr. The turonian, and probably part of the senonian, stage is represented by Rudistæ limestone, with *Radiolites* sp. The maestrichtian is represented by limestone with *Cyclolites regularis* Leymerie, *Hemipneustes* sp., and *Lithothamnion*. A thick bed of coarse, ferruginous sandstone may be of either Cretaceous or Tertiary age. The Tertiary system is represented by gastropod-bearing limestone, overlain by shaly foraminiferal limestone with *Velates schmideliana* Chemn. This is followed by shale, with *Spondylus* sp., overlain by *Orbitolites* limestone. Still higher in the series is a band of richly fossiliferous *Alveolina* limestone. The youngest of the rocks of the Tertiary system is a dark shale ("Dzongbuk shale"), apparently unfossiliferous. The whole series from the ferruginous sandstone up to the Dzongbuk shale is probably of eocene age;

any younger beds that may have overlain the shale have been cut out by a fault which brings the upper Cretaceous over the Tertiary. The table of strata facing Pl. 3 shows the sequence of the Cretaceous and Tertiary beds of the Kampa series.

6. Basic igneous rocks, including dolerite and serpentine, occur as dykes in the Jurassic slates near Gyantse and along the shores of Yamdrok Tso. Granite is found in the valleys of the Tsangpo and Kyi Chu and also at Lhasa, where it is used as a building stone. The Kyi Chu granite is a fairly coarse-grained, hornblende granite, containing oligoclase, biotite and sphene, and differs markedly from the typical biotite-granite of the Himálaya. The difference, however, consists chiefly in the large quantity of lime and lime-silicates occurring in the former rock and may be due to the absorption by it of lime from the sedimentary beds into which it was intruded. Pebbles of dacite and allied volcanic rocks occur in the gravels of the Tsangpo near Chaksam, and are apparently derived from the hills between Shigatse and Kampa-partsi.

A bed of amygdaloidal trap was found among the slates believed to be of Jurassic age in the hills to the north-east of Gyantse. If truly contemporaneous, this bed is of some interest as being the first indication of Jurassic lava flows yet observed in the Himalaya.

7. Few minerals of economic value were found *in situ*; gold occurs in very small quantity in the Tsangpo gravels, and an efflorescence, composed largely of sodium carbonate, is found at Utsi, 6 miles north-west of Kampa dzong.

APPENDIX A.

NOTE ON CONCENTRATES FROM CHAKSAM ON THE TSANGPO.

Two samples of concentrates from the Tsangpo, near Chaksam, were examined by Mr. J. M. Maclaren and described as follows:—No. 1 weighed 500 grains and was the result of washing 112 lbs. of gravel from the left bank of the river, one mile above Chaksam. 399 grains, or 80 per cent., of the concentrate, proved to be magnetite, while the greater part of the remainder was composed of zircons. Of gold, there were only four extremely fine specks, far too fine to be weighable.

No. 2 sample, of 790 grains, was the result of washing 160 lbs. of gravel from the right bank of the Tsangpo above the Chaksam ferry. This contained 612 grains of magnetite sand or 77 per cent., nearly the same as the preceding. The residue of 178 grains was carefully washed and yielded a number of extremely small grains of gold, weighing '02 grain. The total gold content per ton of these gravels is '28 grain, or a little more than $\frac{1}{4}$ grain, of a value of one half-penny.

The minerals associated with the gold are magnetite and zircon, making up, as already stated, nearly the whole of the concentrates. There are also occasional grains of rutile, of tourmaline and of hercynite. With the gold, and impossible to separate from it by ordinary washing, there remained a little dust, which was resolved, under the high powers of the microscope, into black, cubical crystals with cubical cleavage. These, from their extremely high specific gravity, their crystalline form and their colour, are probably uraninite or pitchblende.

The washings were made at a wide portion of the river, and gold was obtained in the dish only when washing was carried on in the coarser gravels, the stones of which ranged up to 6 inches in diameter. There is no record of gold-washing along the Tsangpo, and the poverty of its gravels, as indicated by the above results, confirms previous assumptions that the gold of the Assam valley has not been derived from the Tibetan highlands. The extreme fineness of the gold, combined with its flaky character,—the largest grain is no more than '3 mm. long and '01 mm. thick—indicates a distant source, possibly as far distant as the gold-regions of the Manasarowar lakes.

Sample No. 2 was sent to the Imperial Institute on the suggestion of Professor Wyndham R. Dunstan, F.R.S., in order that a special examination might be made for minerals of the so-called "rare earths," and Professor Dunstan reports as follows:—

The sample was described in the Records of the Geological Survey of India as consisting of 77 per cent. of magnetite, the residue containing zircon, rutile, tourmaline, hercynite, gold and minute cubical crystals, which were supposed to be uraninite but which I suggested might prove to be thorianite. Most of the abovementioned minerals appeared to be present in the sample sent to the Imperial Institute, and monazite in addition, but the residue left after removing the magnetite was only 2'3 per cent. of the total.

A sample of the material was tested in the Wilson electroscope and exhibited slight radio-activity.

The sample gave the following results on analysis :—

Cerium and allied oxides	. . .	Ce_2O_3	0.098 per cent.
Thorium dioxide	. . .	ThO_2	0.054 " "
Uranoso-uranic oxide	. . .	U_3O_8	0.006 " "
Phosphoric oxide	. . .	P_2O_5	0.043 " "

These results indicate that the sample contains about 0.15 per cent. of monazite, and a trace of a thorium-uranium mineral in addition. It is, however, impossible to express any definite opinion regarding the nature of the latter constituent, unless larger quantities can be procured for examination.

APPENDIX B.

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GEOLOGICAL SURVEY OF INDIA

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt. 2, Pl. 1



FIG 1 LOWER AND MIDDLE JURASSIC BEDS, 8 MILES SOUTH OF KAMPA DZONG

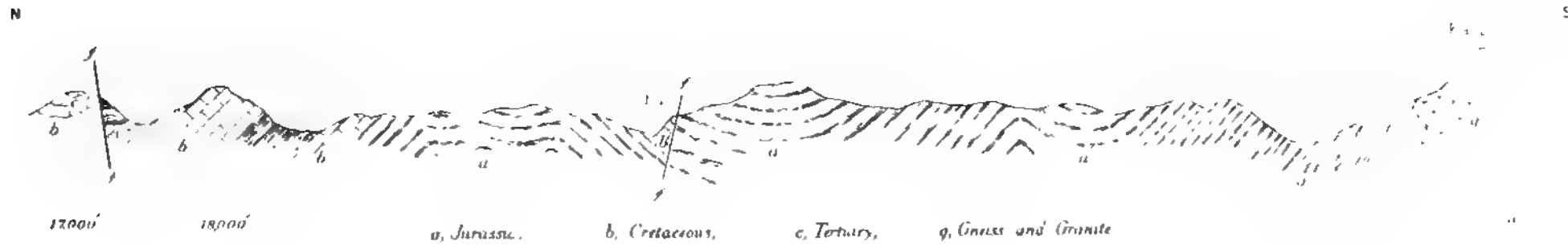
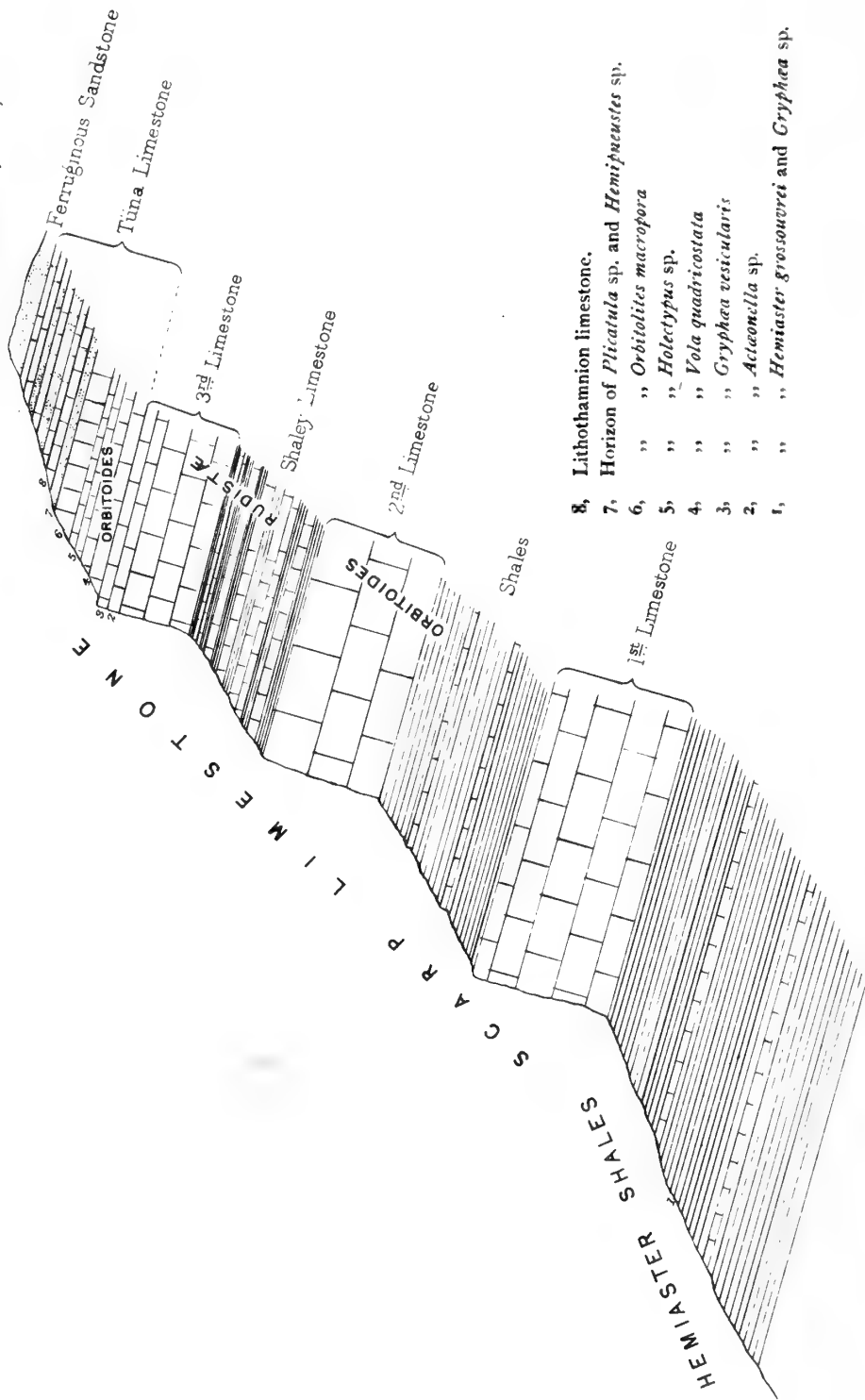


FIG 2 SECTION FROM KANGCHENJHAO TO KAMPA RIDGE

GEOLOGICAL SURVEY OF INDIA

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt. 2, Pl. 2



DIAGRAMMATIC SECTION OF CRETACEOUS BEDS OF KAMPA RIDGE.

EXPLANATION OF PLATE 3.

FIGS. 2 AND 3.

- 17.—Dzongbuk shales.
- 16.—Alveolina limestone.
- 15.—Sandy shales.
- 14.—Orbitolites limestone.
- 13.—Spondylus shales.
- 12.—Operculina limestone.
- 11.—Gastropod limestone.
- 10.—Ferruginous sandstone.
- 9.—Tūna limestone.
- 8.—Third limestone.
- 7.—Shaly limestone.
- 6.—Second limestone.
- 5.—Shales.
- 4.—First limestone.
- 3.—Grey (Hemiaster) shales. } Cenomanian.
- 2.—Kampa shales. }

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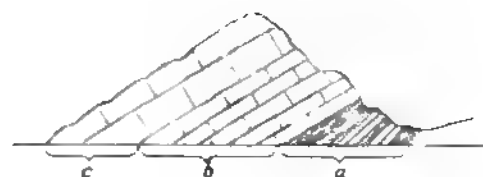


FIG 1 LIMESTONE CLIFF NEAR TSO LHAMO

- a Shale and flaggy sandstone
- b Crushed and splintery limestone oolitic in parts
- c Compact blue limestone with crinoid stems



FIG 2 SECTION ON RIGHT SIDE OF STREAM ABOUT 1½ MILE ABOVE KAMPA DZONG

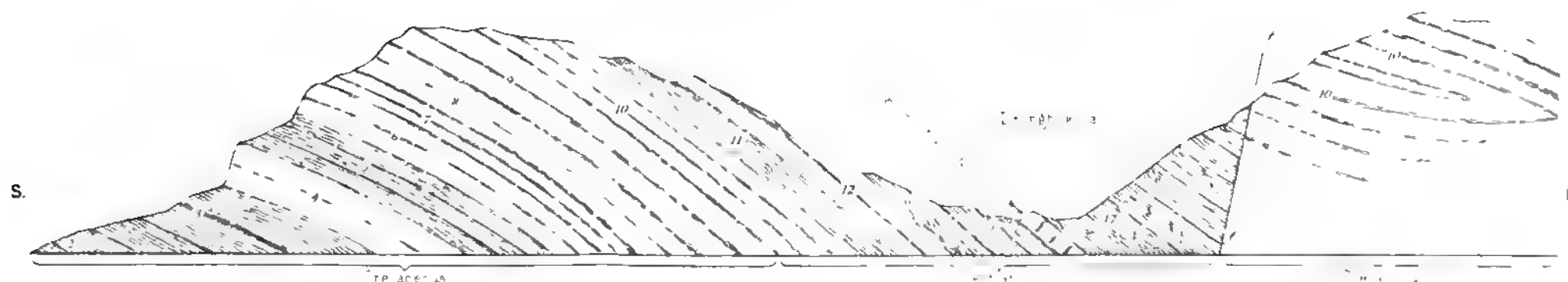
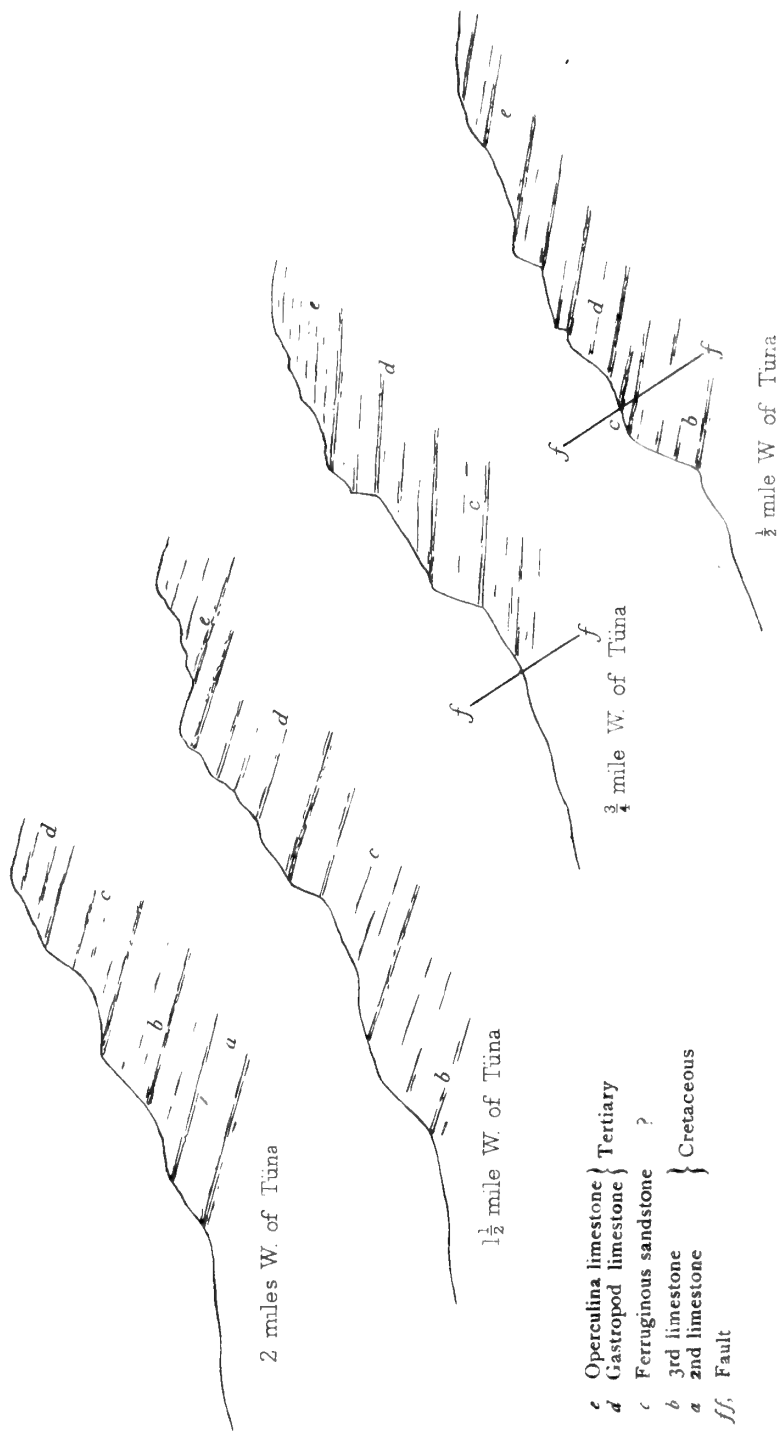


FIG 3 PROBABLE SECTION THROUGH KAMPA RANGE AT OZONGBUK LA

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt. 2, Pl. 4



SOUTHERN SLOPES OF RIDGE RUNNING WEST FROM TUNA.



H. H. HAYDEN, PHOTO.

TSANGPO VALLEY AT CHAK-SAM.

G, granite, D, hornblende diorite.

Geol. Surv. India

GEOLOGICAL SURVEY OF INDIA.

H. H. Hayden.

Memoirs, Vol. XXVI, Pt. 2, Pl. 6.



H. H. Hayden, Photo.

KYI CHHU VALLEY BELOW LHASA.

JURASSIC &
CRETACEOUS

10000 ft.

DREPU N
MONASTERY

6000 ft. above sea level

H. H. Hayden.



J. C. White, Photo.

NORTHERN ARM OF YAM-DROK TSO.

EXPLANATION OF PLATE 8

FIG. 1.

- 3.—Giri limestone (? Neocomian).
- 2.—Jurassic slate and quartzite.
- 1.—Spiti shales.

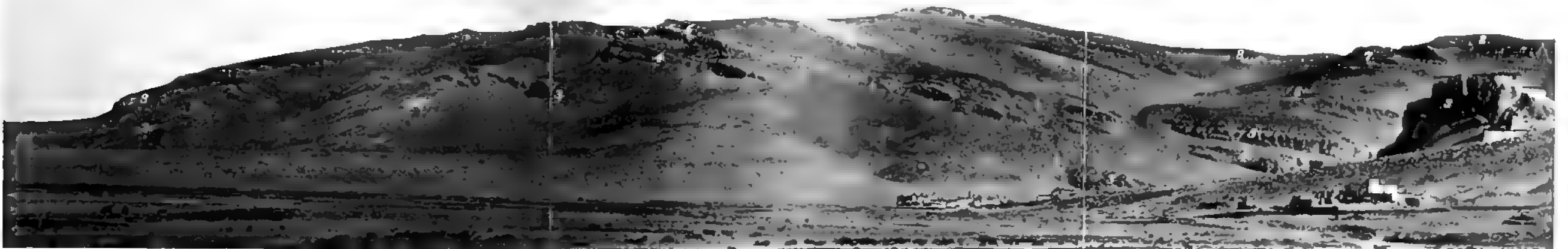
FIG. 2.

- 8 —Operculina limestone.
- 7.—Gastropod limestone.
- 6.—Ferruginous sandstone.
- 5.—Third scarp limestone.
- 4.—Second „ „
- 3.—First „ „
- 2.—Hemiaster shales.
- 1.—Kampa shales.



H. H. Hayden Photo

FIG. 1. KANGCHENJHAO AND CHOMOYUMO FROM THE NORTH



H. H. Hayden Photo

FIG. 2. WESTERN END OF KAMPA RIDGE.

EXPLANATION OF PLATE 9.

FIG. 1.

- 4.—Third scarp limestone.
- 3.—Second „ „
- 2.—First „ „
- 1.—Hemiaster shales.

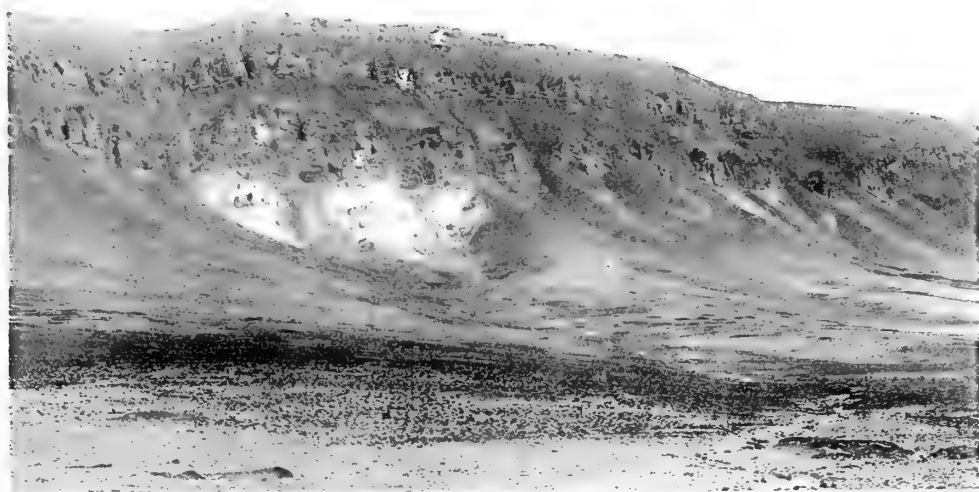
FIG. 2.

- 3.—Cephalopod horizon.
- 2.—Brachiopod horizon.
- 1.—Horizon of *Trigonia costata*.

GEOLOGICAL SURVEY OF INDIA.

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt. 2, Pl. 9.



H. H. Hayden, Photo.

FIG. 1. KAMPA RIDGE, 7 MILES E. OF KAMPA DZONG.



H. H. Hayden, Photo.

Benrose, Collo., Derry.

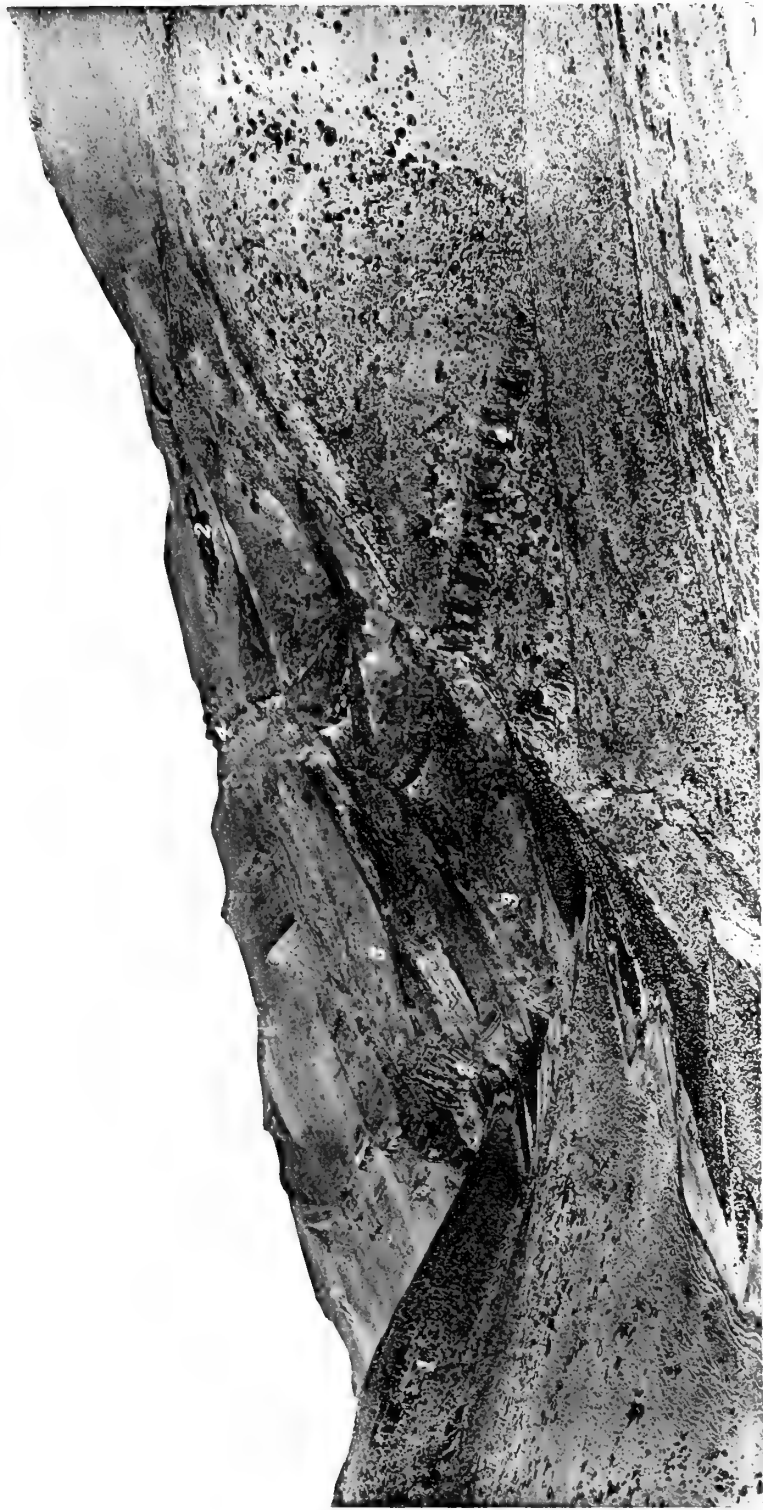
FIG. 2. MIDDLE JURASSIC LIMESTONE, NEAR LUNGMA.

EXPLANATION OF PLATE 10.

- 4.—Orbitolites limestone.
- 3.—Spondylus shales.
- 2.—Operculina limestone.
- 1.—Gastropod limestone.
- f*—*f*.—Strike fault.

GEOLOGICAL SURVEY OF INDIA.

Memors, Vol. XXXVI, Pt. 2, Pl. 10.



TERTIARY BEDS IN KAMPA RAVINE.



EXPLANATION OF PLATE II

FIG. 2.

- 3.—Orbitolites limestone.
- 2.—Spondylus shales.
- 1.—Operculina limestone.



H. H. Hayden, Photo.

FIG 1. FOLDED JURASSIC BEDS 4 MILES WEST OF GYAN-TSE



H. H. Hayden, Photo.

Bemrose, Collection

FIG 2. OPERCULINA LIMESTONE AT KAMPA DZONG.

EXPLANATION OF PLATE 12.

FIG. 1.

- 4.—Operculina limestone.
- 3.—Gastropod limestone.
- 2.—Ferruginous sandstone.
- 1.—Tūna limestone.

FIG 2.

- 3.—Operculina limestone.
- 2.—Gastropod limestone.
- 1.—Ferruginous sandstone.
- + Fossiliferous horizon.



H. H. Hayden. Photo.

FIG. 1. FAULT THROUGH NORTHERN RIDGE BEHIND KAMPA DZONG.

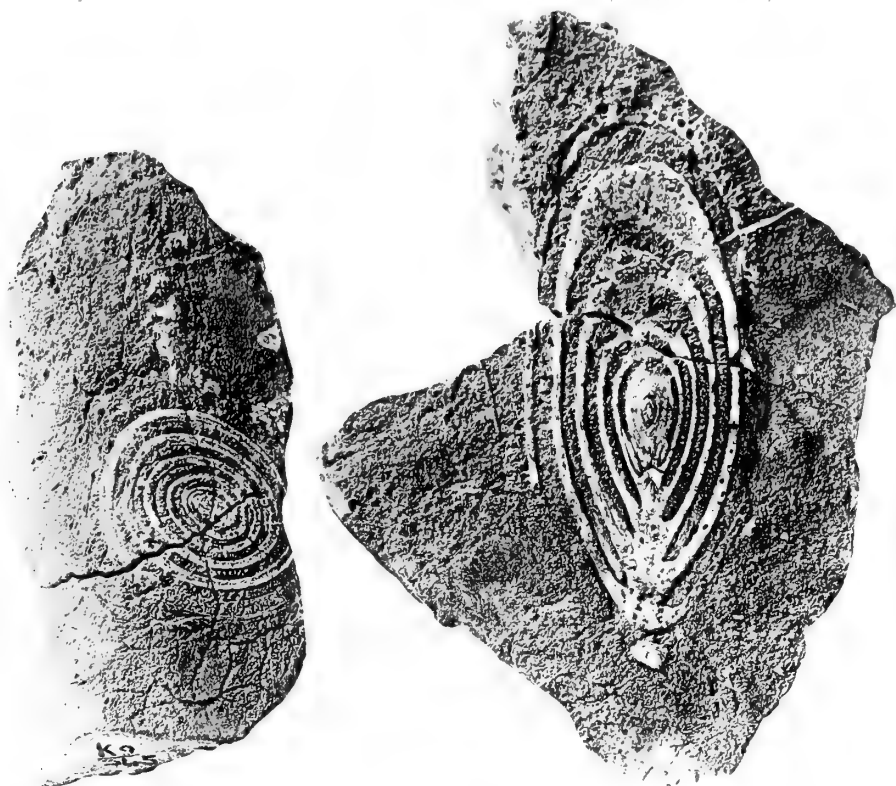


H. H. Hayden, Photo.

Bemrose, Colo., Derby.

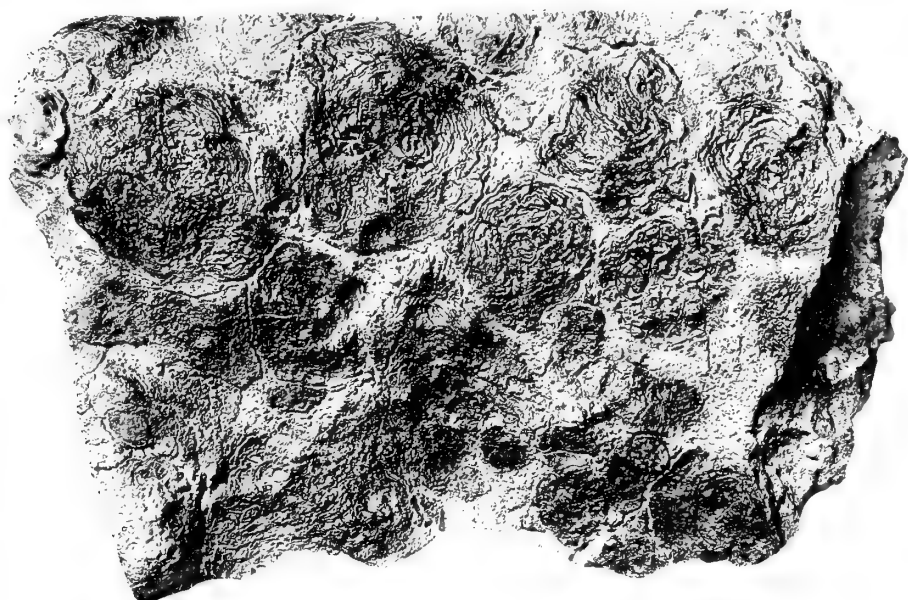
FIG. 2. TERTIARY BEDS NEAR TU-NA.





H. B. W. Garrick, Photo.

FIG. 1. ACTÆONELLA LIMESTONE.



H. B. W. Garrick, Photo.

Bemrose, Collo., Derby.

FIG. 2. LITHOTHAMNION LIMESTONE.



GEOLOGICAL SURVEY OF INDIA

H. H. Hayden.

Memoirs, Vol. XXXVI, Pt 2, Pl, 14.

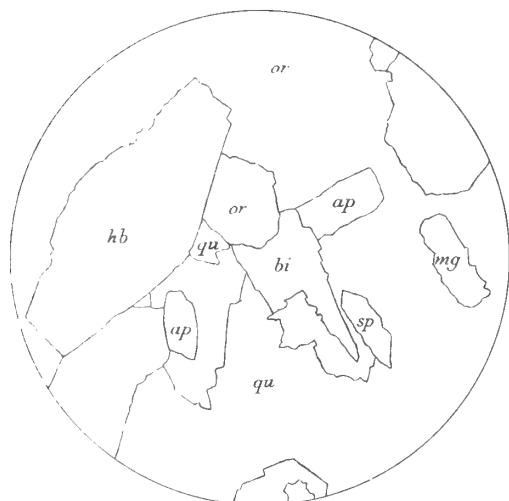


Fig. 1. Granite from Lhasa

hb. Hornblende
or. Orthoclase
qu. Quartz
ap. Apatite
bi. Biotite
sp. Sphene
mg. Magnetite

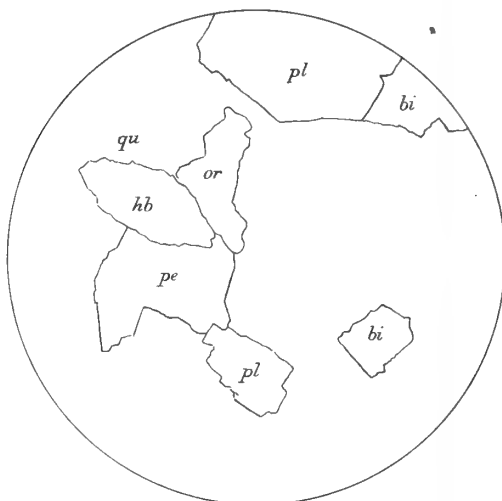


Fig. 2. Granite from Lhasa

hb. Twinned crystal of hornblende
bi. Biotite
pl. Plagioclase
or. Orthoclase
pe. Perthite

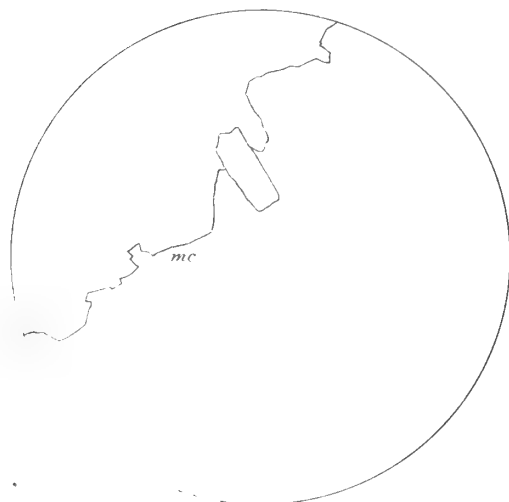


Fig. 3. Granite from Chushul, Tsangpo R.

mc. Microcline



Fig. 4. Lhasa Granite (same slide as fig. 1)

ca. Calcite
or. Parts of a single crystal of orthoclase
sp. Sphene
ep. Epidote
qu. Quartz
pl. Plagioclase

GEOLOGICAL SURVEY OF INDIA.

H. H. Hayden.

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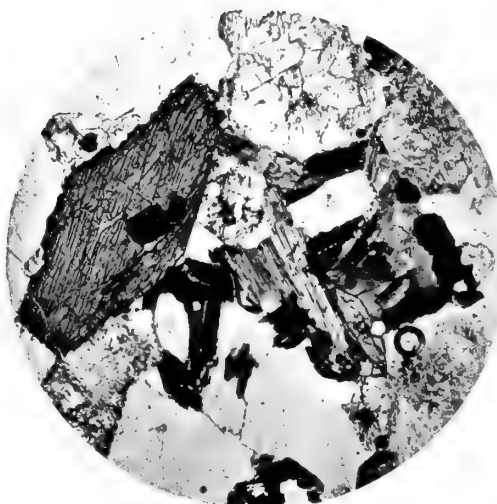


FIG. 1.



FIG. 2.



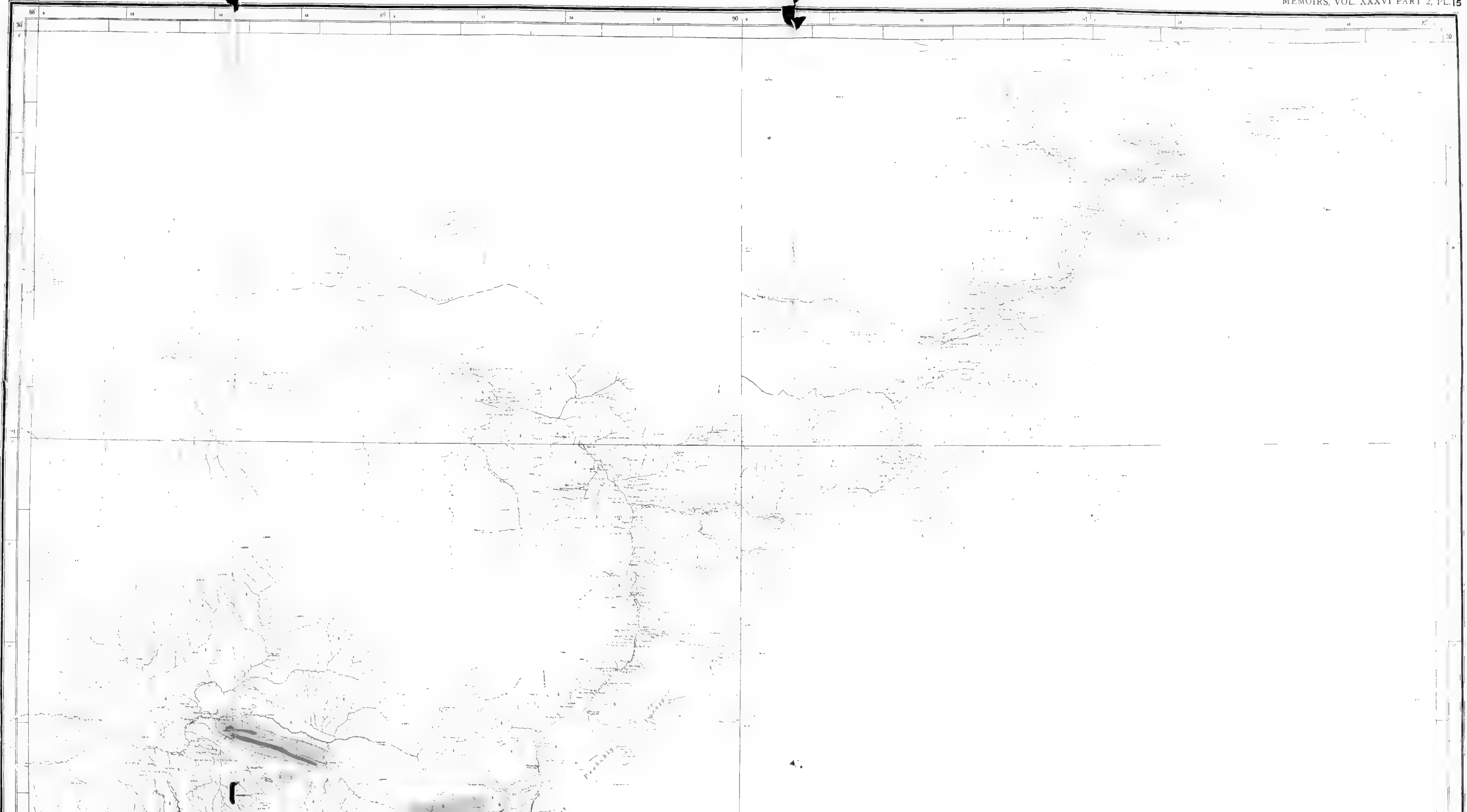
FIG. 3.



FIG. 4.

H. H. Hayden, Photo.

Bemrose, Collo., Derby





MEMOIRS
OF
THE GEOLOGICAL SURVEY OF INDIA

MEMOIRS
OF
THE GEOLOGICAL SURVEY OF INDIA

VOLUME XXXVI, PART 3

THE TRIAS OF THE HIMÁLAYAS. *By* C. DIENER, PH.D.,
Professor of Palæontology at the University of Vienna

Published by order of the Government of India

CALCUTTA :
SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY OF INDIA,
27, CHOWRINGHEE ROAD
LONDON : MESSRS. KEGAN PAUL, TRENCH, TRUBNER & CO.
BERLIN : MESSRS. FRIEDLÄNDER UND SOHN

1912.

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

THE TRIAS OF THE HIMÁLAYAS. *By* C. DIENER, PH.D.,
Professor of Palæontology at the University of Vienna.

I.—INTRODUCTION.

In a note accompanying the description of the Muschelkalk in Spiti in the first part of the present volume by H. Hayden (page 72), and in a chapter treating with the correlation of the Mesozoic beds of Spiti with those of other parts of India and of Europe (page 88) it was proposed to devote a second part of this volume to a summary of the Trias of the Himálayas.

A paper treating with this subject, which had been left by the late Dr. A. v. Krafft in 1901, was entrusted to me for a careful revision by C. L. Griesbach, then Director of the Geological Survey of India. But the fragmentary character of the paper, consisting only of scattered and unarranged notes, induced me to postpone this task, until the palæontological descriptions of the new materials from the Triassic rocks of the Himálayas had been finished. The advisability of basing a summary of the Trias of the Himálaya on the results of an examination of the entire stratigraphical and fossil materials then available, was obvious.

This examination being now finished and the geological exploration of the Central Himálayas having come to a close for several seasons, a detailed paper on this subject is justified. This paper, however, can hardly be called a revision of A. v. Krafft's original notes, but is almost entirely my own work.

Fourteen years have elapsed since the publication of the results of the expedition of 1892, in which Griesbach, Middlemiss and I took part. Shortly afterwards the study of the sedimentary deposits of the Himálayas was resumed; areas formerly known only more or less superficially, were re-examined in greater detail and a very large amount of new fossil material has been obtained. Both the observations in the field, which are chiefly due to H. Hayden, A. von Krafft, La Touche, Smith, Noetling and Walker, and the subsequent examination of the collections have increased our knowledge considerably, particularly so with respect to the Trias. While formerly only the sections of Painkhanda (Shal-shal cliff, Babinag cliff) were known in any detail, we have now equally detailed accounts of those in Spiti and considerable additions have been made to our knowledge of those in Eastern Johar and Byans and in the region of the exotic blocks between Malla Johar and Hundes. It therefore seems possible now to make an attempt to correlate those four different areas.

Recent researches tend to show that the Trias, far from being developed uniformly throughout the length and breadth of the Himálayas, has some very marked geographical peculiarities. We can no longer characterise any individual section as a "type-section" of the Himálayan Trias. To do so would, indeed, be as incorrect as to speak of a particular section in the South-eastern Tirol or in the Salzkammergut as a type-section of the Alpine Trias.

In fact the Himálayan Trias clearly shows those changes of facies which are common to most sedimentary deposits of marine origin, and which, if not so rapid or abrupt as in the case of the Alpine Trias, are yet almost equally marked. This becomes especially evident from a comparison of the sections of Byans and Malla Johar with those of Spiti and Painkhanda.

My examination of the fossil collections made by Hayden and A. v. Krafft in Spiti and Malla Johar and my revision of A. v. Krafft's memoir on the Cephalopoda of the Lower Trias have delayed the writing of this paper for a longer period than I had anticipated. This delay, however, has enabled me to include many new facts, which were not known to Noetling, when publishing his summary of the Trias of Asia in *Lethæa mesozoica* (Vol. I, Pt. 2, Stuttgart, 1905). A direct comparison will, I trust, convince the reader that the present paper has not been rendered altogether unnecessary by Noetling's memoir.

II.—LITERATURE.

Before entering upon a description of the Triassic sediments of the Himálayas, a short historical retrospect of the development of our knowledge of those deposits may be deemed appropriate.

The credit of the discovery of Triassic deposits in the Central Himálayas is due to Captain (afterwards General Sir Richard) Strachey,¹ who in 1851 mentioned their presence in several localities in the neighbourhood of the Niti Pass. Their correlation with the beds of St. Cassian by Greenough (1855), by E. Suess² (1862) and by T. W. Salter³ (1865) was based on an examination of the fossils, which had been collected by Strachey from loose blocks, not *in situ*.

Although the defective state of our knowledge of the stratigraphy of the Alpine Trias and the wide range of interpretation adopted in Triassic species of Cephalopoda prevented any attempt at an exact correlation at that time, the general statement of a remarkable analogy with the Alpine Trias has been proved to be correct.

The existence of Triassic beds was confirmed by an examination of fossils, which had been collected in Spiti and Hundes by Dr. Gerard and by the brothers von Schlagintweit.

H. F. Blanford⁴ described the Gerard collection and proved one of the Triassic species of ammonites (*Ptychites Gerardi* Blfd.) to belong to a genus characteristic of the Alpine Muschelkalk.

The Cephalopoda of the Schlagintweit collections were examined by A. Opper,⁵ the brachiopods and bivalves by C. W. Guembel.⁶ Opper

¹ R. Strachey : On the geology of part of the Himálaya Mountains and Tibet, *Quart. Journ. Geol. Soc.*, VII, 1851, pp. 292-310.

² E. Suess : *Verhandl. K. K. Geol. Reichsanst., Wien*, XII, p. 255 (Sitzg. 31, Juli 1862).

³ T. W. Salter and H. F. Blanford : *Palæontology of Niti in the Northern Himalayas*, Calcutta, 1865.

⁴ H. F. Blanford : On Dr. Gerard's collection of fossils from the Spiti valley in the Asiatic Society's Museum. *Journal Asiat. Soc. of Bengal*, 1863, No. 2, pp. 121-138.

⁵ A. Opper : Ueber Ostindische Fossilreste aus den sekundaeren Ablagerungen von Spiti and Gnari Khorsum in Tibet. *Palæontol. Mittheilungen aus dem Museum des Kgl. bayrischen Staates*, I, p. 267.

⁶ C. W. Guembel : Ueber das Vorkommen von unteren Triassschichten in Hochasien (nach den von den Gebruedern von Schlagintweit gesammelten Fundstuecken beurteilt). *Sitzgsber. Kgl. bayr. Akad. d. Wiss. Muenchen*, 1865 (XI), pp. 348-366.

recognised the Triassic character of seventeen species of ammonites. Guembel assigned three species of bivalves to the Buntsandstein.

In the meantime E. Beyrich¹ proved the ammonites described by Oppel to be of Muschelkalk age.

Thus the presence of two different Triassic horizons had been established in the Himálayas, of the Lower Trias (Buntsandstein) in a bivalve-bearing facies, and of the Muschelkalk in a facies of dark limestone rich in Cephalopoda. But this establishment had been based on the study of fossils only discovered by travellers in different parts of the sedimentary belt of the great range. Stratigraphical observations in the field were still entirely wanting.

Stoliczka was the first author, who gave a rough outline of the stratigraphy of the Himálayas after having visited a number of sections in Spiti and Rupshu in 1864.² His system was one strictly based upon the simple practice of giving a geographical name to a rock group, without reference of each particular local group to a place in the stratigraphical standard scale. His views have been adopted by the authors of the "Manual of the Geology of India." Both his general classification of the Himálayan Trias and its correlation with the homotaxial rock groups in Europe have required some modifications, in order to bring them into line with our more extensive knowledge.

Stoliczka grouped the sedimentary formations between the Silurian (Muth series) and the Lias (Tagling limestone) into three divisions. He distinguished, in descending order :—

3. Para limestone, corresponding to the rhætic stage (Dachsteinkalk of Austrian geologists).
2. Lilang series, Upper Trias, corresponding to the beds of Hallstatt and St. Cassian.
1. Kuling series, Carboniferous.

Stoliczka believed the Upper Trias to rest immediately on the Carboniferous and failed to recognise the Lower and Middle Trias. Without depreciating the value of Stoliczka's stratigraphical results it is neces-

¹ E. Beyrich : Ueber einige Cephalopoden aus dem Muschelkalk der Alpen und ueber verwandte Arten, *Abhandl. Kgl. Akad. d. Wiss. Berlin*, 1866, No. 2, pp. 105-179.

² F. Stoliczka : Geological sections across the Himálaya Mountains from Wangtu bridge on the river Sutlej to Sungdo on the Indus. *Mem. Geol. Surv. of India*, Vol. V, Pt. 1, 1865, pp. 1-154.

sary to lay special stress on this fact, because Noetling in his historical retrospect¹ somewhat exaggerates the importance of Stoliczka's work in Spiti affirming with great confidence that the only progress in the stratigraphy of the Trias since Stoliczka's memoir is marked by the discovery of the Lower Trias within the Lilang series.

Stoliczka was particularly unfortunate in confining his attention to the Kuling section, which he presumably accepted as a typical one, whereas subsequent researches have shown the Lower Trias to be cut out there by a fault, which causes the Daonella shales to lie directly on the Productus shales. We may, however, admit that his overlooking the Lower Trias is easily explained by his short visit to the Spiti sections and that his correlation of the entire Lilang series with the Upper Trias is pardonable, fossils of the Muschelkalk having been found, but not recognised as such before Stoliczka's survey began.

There is, however, no doubt that considering the circumstances under which he worked, Stoliczka's stratigraphical results were most valuable. To him belongs the credit of having been the true pioneer of Himálayan stratigraphy.

Very considerable progress was subsequently made by C. L. Griesbach, who succeeded Stoliczka in the geological exploration of the Himálayas and in 1880 gave the first systematic account of the Triassic system.² All subsequent accounts of the Himálayan Trias must needs be based on his work.

He was the first to discover the Lower Trias and the Muschelkalk *in situ*. In a preliminary note on his first season's work in the Himálayas he gave a detailed description of the section of the Shalshal cliff near Rimkin Paiar, in Painkhanda, together with description and figures of the fossils characteristic of the *Otoceras* horizon, which was then considered by him as a passage bed between the Permian and Triassic systems.³ In the Upper Trias he distinguished a number of subdivisions, which still remain unaltered, although the knowledge of their fossils has led to a correlation with Alpine Triassic stages, differing widely from that which had been established by Griesbach.

¹ F. Noetling, Asiatische Trias, *Lethæa mesozoica*, 1. c., p. 125.

² C. L. Griesbach : Geological notes, *Records, Geol. Surv. of India*, XIII, 1880, pp. 83-93.

³ C. L. Griesbach : Palæontological notes on the lower Trias of the Himálayas, *ibid.*, XIII, pp. 94-113, XIV, pp. 154, 155.

In 1883 C. L. Griesbach visited Spiti in order to remove certain discrepancies between Stoliczka's description and his own observations in the Central Himálayas of Kumaon and Garhwal. He was able to show that Stoliczka's Kuling shales were of Permian age and followed conformably by the Lower Trias and by the Muschelkalk, which Stoliczka had failed to recognise in his Triassic sections.¹

In the meantime the survey of Kashmir and Ladakh had been brought to a close by R. Lydekker. He made an attempt to identify in Kashmir the subdivisions established by Stoliczka in Spiti. Being obliged by the difficulty of the terrane to include in one single group—his "Supra-Kuling series" all the beds from the Lilang series upwards to the Chikkim limestone, he was not able to establish any subdivisions of the Triassic rocks, which he found, however, widely distributed throughout the district, which had been surveyed by him during the years 1875 to 1882.²

In 1891 C. L. Griesbach published his memoir on the geology of the Central Himálayas.³

This is, indeed, a standard work to the student of Himálayan geology, dealing with the vast area of high ranges of Garhwal and Kumaon, including Byans and some of the adjoining parts of Hundes.

The fossil Cephalopoda collected by him in his researches were sent to Vienna and examined by E. v. Mojsisovics.⁴ They indicated the existence of several Triassic localities and horizons sufficiently rich in fossils to encourage the promotion of a special expedition into the Central Himálayas. This joint expedition of the Imperial Academy of Vienna and of the Geological Survey of India (May to October 1892), in which Diener, Griesbach and Middlemiss took part, made a detailed survey of the Bambanag and Shalshal cliff sections and had the good fortune to discover the remarkable region of exotic blocks near Chitichun No. 1.

¹ C. L. Griesbach : Geological notes, *Records, Geol. Surv. of India*, XXII, 1889, pp. 158, 167.

² R. Lydekker : The Geology of the Kashmir and Chamba territories, and the British district of Khagan. *Mem., Geol. Surv. of India*, Vol. XXII, 1883.

³ C. L. Griesbach : Geology of the Central Himálayas. *Mem., Geol. Surv. of India*, Vol. XXIII, 1891.

⁴ E. v. Mojsisovics : Vorläufige Bemerkungen ueber die Cephalopodenfaunen der Himálaya-Trias. *Sitzsber-Kais. Akad. d. Wissensch. C. I.*, Abt. 1. p. 272.

Large collections from all the fossiliferous Triassic beds were obtained, but Griesbach's classification of the Triassic system underwent only slight modification. The most important, perhaps, was the evidence—supported by the palæontological researches of Bittner and F. E. Suess—that beds with Koessen types were not known to occur in the Himálayas of Painkhanda and Johar, and that Griesbach's "Upper Rhætic" is in fact younger, probably Lias. The boundary between the Triassic and Jurassic systems is consequently to be drawn considerably lower in the sequence of beds than was done by Griesbach.

In addition to Diener's detailed account of the stratigraphical results of the expedition in 1892,¹ C. Diener,² E. v. Mojsisovics³ and A. Bittner⁴ have published exhaustive descriptions of the various Triassic fossil faunæ in series XV of the *Palæontologia Indica*.

Those palæontological researches offered the possibility of a detailed comparison of the succession of the individual Triassic faunæ both in the Himálayas and in the Eastern Alps. They might even seem to justify the opinion that our knowledge of the Himálayan Trias had arrived at a point beyond which no new results of any great importance could be expected. But although this may be true to some extent with regard to the sections of Painkhanda and Western Johar, the Trias of the Himálayas as a whole was by no means known in great detail.

Even in the two classical sections of the Bambanag and Shalshal cliffs two gaps had to be filled by later examinations, the absence of the ladinic stage and of beds representing the zone of *Tropites subbullatus*. On the other hand considerable interest in Himálayan geology had been aroused by the memoirs mentioned above.

After several years' intermission the geological survey of the higher ranges of the Himálayas was resumed in 1898. H. Hayden was deputed to Spiti and made detailed studies in the Palæozoic and Triassic regions

¹ C. Diener : Ergebnisse einer geologischen Expedition in den Central Himálaya von Johar, Hundus und Painkhanda, *Denkschr. Kais. Akad. d. Wiss.*, LXII, 1895, pp. 533-608.

² C. Diener : Cephalopoda of the Muschelkalk, Himálayan Fossils, *Palæontologia Indica*, ser. XV, Vol. II, Pt. 2, (1895). Cephalopoda of the Lower Trias, *ibidem* Vol. II, Pt. 1, (1897).

³ E. v. Mojsisovics : Upper Triassic Cephalopoda faunæ of the Himálayas, *ibidem* Vol. III, Pt. 1, (1899). The German original was published in 1896 in Vol. LXIII of the *Denkschr. d. Kais. Akad. d. Wissensch.*

⁴ A. Bittner : Trias Brachiopoda and Lamellibranchiata of the Himálayas, *Palæontologia Indica*, l. c., Vol. III, Pt. 2, (1899).

of the upper Pin valley and adjoining areas. The survey work was continued in Spiti during the summer of 1899 by H. Hayden and A. von Krafft. The Triassic beds were found to be of greater thickness and to contain a larger number of fossiliferous horizons than in the sections of Painkhanda studied by Griesbach and Diener. Three distinct stratigraphical horizons were observed in the Lower Trias (Scythian stage) and an equal number in the Muschelkalk. Both the ladinic stage and the zone of *Tropites subbullatus*, which Griesbach and Diener had failed to recognise in Painkhanda, proved to be especially well developed. At the base of the Dachsteinkalk a series of quartzites and shales, not known from the Bambanag and Shalshal cliffs, were found to constitute a well-marked stratigraphical horizon.¹

In the season of 1898 T. H. D. La Touche was charged with a detailed survey of the upper Lissar valley and F. H. Smith with the survey of Byans. The work of the latter geologist was resumed in 1900 by A. v. Krafft. Large collections were made from the Lower Trias, the Muschelkalk, and the *Tropites* limestone. Descriptions and figures of the fauna of the latter were published by Diener in Vol. V of the "Himálayan Fossils."²

After his survey of Byans A. v. Krafft visited the sections of the Bambanag and Shalshal cliffs, in order to make a comparison with the Spiti sections based on personal examination.

He was able to prove the ladinic stage to be represented there, although poor in fossils and extremely reduced in thickness. He also found his classification of the Muschelkalk, as adopted for Spiti, to be correct. On the progress attained by him with respect to the subdivisions of the Muschelkalk, he has reported in a special paper.³

Both in the Halorites beds and in the *Traumatocrinus* limestone he collected a large number of fossils, which were examined subsequently by C. Diener.⁴

¹ A. v. Krafft: Stratigraphical notes on the mesozoic rocks of Spiti, *General Report, Geol. Surv. of India*, 1899-1900, pp. 199-220.

² C. Diener: The fauna of the *Tropites* limestone of Byans. *Palaeontologia Indica*, ser. XV, Vol. V, Pt. 1, (1906).

³ A. v. Krafft: Zur Gliederung des Muschelkalkes im Himálaya. *Verhandl. K. K. Geol. Reichsanst.*, 1901, p. 52.

⁴ C. Diener: Note on some fossils from the Halorites limestone of the Bambanag cliff (Kumaon), collected by the late Dr. A. v. Krafft. in the year 1900. *Records, Geol. Surv. of India*, Vol. XXXIV, 1906, pp. 1-11. The fauna of the *Traumatocrinus* limestone. *Palaeont. Ind.*, ser. XV, Vol. VI, Pt. 2, (1909).

A. v. Krafft's greatest success was the discovery of rich Triassic and Liassic faunæ in the exotic blocks of Malla Johar, where the Mesozoic beds are developed in a facies differing completely from the normal facies of the main sedimentary belt of the Central Himálayas. The stratigraphical and tectonic results of his survey have been summarized in a very interesting paper.¹ Soon after having finished his manuscript, he died suddenly on the 22nd September 1901. By his death the Geological Survey of India suffered the loss of a most valuable Himálayan explorer.

In 1900 a new problem came up, concerning particularly the correlation of the Lower Triassic beds of the Himálayas and the Salt Range.

In the Salt Range, which had given the most perfect sections of upper Palæozoic and Lower Triassic formations, there appeared a complete series of beds distinguished by easily recognised differences in their lithological characters and in their fossils. A lower division, the *Productus* limestone, had been assigned to the Permian, and an upper one, the *Ceratite* formation to the Triassic system.

Noetling's researches in the Salt Range had led him to views regarding the Permo-Triassic boundary in the *Ceratite* beds which differed considerably from those of previous workers both in that area and in the Central Himálayas. In 1900 he visited the sections of the Shalshal cliff and of the vicinity of the Niti Pass, in order to study the boundary between the undoubted Permian and the *Otoceras* beds. His proposal to draw the actual boundary between the Permian and Triassic systems above the top of the *Otoceras* beds, has given rise to a careful discussion of all the points, in which he and Diener differed in their interpretation.

In this discussion Noetling was supported by A. v. Krafft, Diener by J. P. Smith.²

¹ A. v. Krafft : Notes on the exotic blocks of Malla Johar in the Bhot Mahals of Kumaon. *Mem. Geol. Surv. of India*, Vol. XXXII, Pt. 3, 1902.—For descriptions and figures of fossils, *vide* C. Diener, Triassic and Liassic faunæ from the exotic blocks of Malla Johar in the Bhot Mahals of Kumaon. *Palæont. Ind.*, ser. XV, Vol. I, Pt. 1, (1908).

² F. Noetling : Die *Otoceras* beds in India. *Centralblatt f. Mineral.*, etc., 1900, p. 216, and *General Report, Geol. Surv. of India* for 1900-01, p. 28. A. v. Krafft :

After the death of A. v. Krafft the task of finishing the survey of Spiti and Rupshu devolved upon H. Hayden. The results of his work carried out during the three seasons of 1898, 1899 and 1901, were exposed in a memoir, in which the chapter dealing with the Triassic rocks, has been based chiefly on the notes left by his late companion in the field.¹

Of the rich fossil materials collected by those distinguished officers in the Muschelkalk and in the Upper Trias only a cursory examination had been made by A. v. Krafft.² A full account, with the descriptions and figures of new forms discovered since 1897, was published in the *Palæontologia Indica* by Diener,³ who also undertook the work of revising and editing a monograph of the Cephalopoda from the Lower Trias, which had been left unfinished by A. v. Krafft in 1901.⁴

A synopsis of the stratigraphy of the Trias in Asia by F. Noetling,⁵ which appeared in 1905, deserves special mention. As I shall have to refer to this memoir repeatedly, a short abstract will be found useful.

As the best representative of the Indo-Chinese zoogeographical province, the Trias of the Himálayas is treated rather extensively. The boundary between the Permian and Triassic systems is drawn by Noetling above the Otoceras beds, according to his views expressed in 1900. The Trias begins with the zone of *Proptychites* (*Prionolobus*) *Markhami* Dien., and includes ten cephalopod-bearing horizons,

Ueber das permische Alter der Otoceras-Stufe des Himálaya. *Centralblatt f. Mineral.* 1901, p. 275; C. Diener: Ueber das Alter der Otoceras beds des Himálaya, *ibidem*, p. 510; C. Diener: Zur Frage des Alters der Otoceras beds im Himálaya, *ibid.*, p. 655. F. Noetling in F. Frech, *Lethæa Palæozoica*, II, Dyas, p. 653; F. Noetling: Ueber das Alter der Otoceras Schichten von Rimkin Paiar (*Painkhanda*) im Himálaya. *Neues Jahrb. f. Mineral*, Beil. Bd. XVIII, p. 258. C. Diener: Ueber die stratigraphische Stellung der Otoceras beds des Himálaya, *Centralbl. f. Mineral*, 1905, pp. 1-9, 36-45.

¹ H. Hayden: The geology of Spiti, with parts of Bashahr and Rupshu, *Mem. Geol. Surv. of India*, Vol. XXXVI, Pt. 1, 1904.

² A. v. Krafft: *General Report Geol. Surv. of India*, 1898-99, pp. 11-12.

³ C. Diener: The fauna of the Himálayan Muschelkalk, *Palæont. Indica*, ser. XV, Himálayan, Foss. Vol. V, Pt. 2, (1907); Ladinic, carni and noric fauna of Spiti, *ibidem*, Vol. V, Pt. 3, (1908).

⁴ *Palæontologia Indica*, ser. XV, Himál. Foss., Vol. VI, Pt. 1, (1909).

⁵ F. Noetling: Die asiatische Trias, *Lethæa geognostica*, II, Teil, Das Mesozoicum, Bd. 1, Trias, 2. Liefg., Stuttgart, Schweizerbart, 1905.

distinguished by their fauna. Those horizons are enumerated by Noetling, as follows :—

Upper Trias	{	10. <i>Sagenites</i> beds.
		9. <i>Halorites</i> beds.
		8. <i>Hauerites</i> beds.
		7. <i>Tropites</i> beds.
Middle Trias	{	6. <i>Joannites</i> beds.
		5. <i>Ptychites</i> beds.
		4. <i>Robustites</i> beds.
Lower Trias	{	3. <i>Stephanites</i> beds.
		2. <i>Hedenstræmia</i> beds.
		1. <i>Prionolobus</i> beds.

Regarding the Lower Trias, Noetling admits that the *Stephanites* beds¹ are only known from Byans and that there is no evidence of their being overlain directly by the *Robustites* beds (with *Ceratites subrobustus*).

He considers the mass of unfossiliferous limestone resting conformably on the horizon of *Rhynchonella Griesbachi* and followed by the beds containing *Spiriferina Stracheyi* as the lowest element of the Middle Trias (Muschelkalk); for this mass of limestones the name of Niti limestone is introduced.

In Spiti the boundary line between the ladinic and carnic stages is drawn by him right across the Grey beds, although their basal Cephalopod horizon with *Joannites cymbiformis* contains a fauna of decidedly carnic habit. The Daonella beds with *Halobia comata* of the Shalshal cliff are also correlated erroneously with the ladinic stage (page 147).

The great difference in the thickness of nearly all the zones of Upper Triassic age in Spiti and Painkhanda which is abundantly evident from A. v. Krafft's sections, is considered doubtful. The affinities between the Himálayan and Alpine faunæ of Middle and Upper Triassic age appear to him rather distant. "The affinities with the Alpine Trias are marked by a general relationship, by the association of various genera only (page 158).² The faunæ of Lower Triassic age have no affinity whatever with those of the Eastern Alps. There is, indeed,

¹ The genus *Stephanites* is altogether unknown from the Lower Trias of the Himálayas.

² This statement is contradicted by a footnote, which has been added by Frech.

no strict evidence for the homotaxy with the Buntsandstein of the beds underlying the Niti limestone."

The annexed table clearly shows the progress which has been made in the classification of the Himálayan Trias since 1865.

The stratigraphy of the Trias in the Central Himálayas is fixed with sufficient certainty now to exclude the probability of any considerable alterations in the sequence of horizons. It is necessary to lay special stress on the fact that, even where differences of opinion still exist between two authors—as for instance in the case of the question of the Permo-Triassic boundary—those authors agree in their views concerning the local stratigraphy, as established in the classical sections of Spiti and Painkhanda. It is in the interpretation of the facts observed that they differ, not in the facts themselves.

Stoliczka Spiti, 1864.	Griesbach Pankhanda, 1891.	Diener Pankhanda, 1895.	Hayden and A. v. Kraft, Spiti, 1904.
Lower Tagling limestone = Kessen beds (Lower Lias) Para Limestone = Rhetic.	13. Grey crinoid limestone thick bedded, with intercalated shales, rich in brachiopods and bivalves.	13. Thin bedded limestones, with many bivalves.	19. Megalodon limestone.
	12. Lithodendron limestone, interbedded with sand- stones, crinoid limestone and shales, with Kessen types. Dachsteinkalk Hauptdolomit (Lower Rhetic)	12. Stratified limestones, with Lithodendron and crinoids, Megalodus le. massive or thick bedded dolomites and limestones.	18. Quartzite series with <i>Spiriferina Griesbachi</i> .
Iilang series = upper Trias.	11. Thick bedded limestone with <i>Megalodon</i> .		17. Monotis shales 16. Coral limestone with <i>Spiriferina Griesbachi</i> . 15. Juvavites beds.
	10. Dolomite and limestone.		
Kuling series = Carboniferous.	9. Liver coloured limestone and greenish shales with <i>Cordia Meltingi</i> .	11. Liver coloured limestone with <i>Sagenites</i> . Noric stage	14. Tropites beds. 13. Grey shales. 12. Halobia beds.
	8. Greenish grey shales and shaly limestone with <i>Spirifer lilangensis</i> .	10. Dolomitic limestones with <i>Spiriferina Gries- bachi</i> .	11. Daonella limestone. Ladinic stage.
Lydekker Kash- miri, 1883.	7. Hard grey limestone, marly and shaly beds, with <i>Tropites Feistman- i</i> .	9. Halorites beds. 8. Hauerites beds.	10. Daonella shales.
	6. Black limestones and splintery black shales (Daonella beds).	7. Shales and limestones with <i>Cladites</i> cf. <i>sub- tornatus</i> , Daonella beds. 6. Traumatoceras 16., with <i>Juamites cymbiformis</i> .	9. Limestone with <i>Ptychites</i> <i>rugifer</i> . 8. Zone of <i>Spiriferina</i> <i>Stracheyi</i> and <i>Ceratites</i> <i>subrobustus</i> . 7. Nodular limestone.
Supra-Kuling series (in part).	5. Hard grey limestone, with <i>Ptychites Gerardi</i> . 4. Earthy limestone, with <i>Rhynchonella</i> cf. <i>semi- pecta</i> var.	5. Massive and stratified limestone with <i>Ptychites</i> <i>rugifer</i> . 4. Earthy limestone with <i>Sibirites Prachiada</i> and <i>Rhynchonella Griesbachi</i> .	6. Shaly ls. with <i>Rhyncho- nella Griesbachi</i> . 5. Hedenstruemia beds. 4. <i>Meekoceras</i> zone. 3. <i>Ophiceras</i> zone.
Kuling series = Carboniferous.	3. Black limestones and shales with <i>Norites</i> <i>planatata</i> . 2. Black limestones and shales with <i>Otoceras</i> <i>Woodwardi</i> .	3. Subrobustus beds. 2. Otoceras beds.	2. <i>Otoceras</i> zone. ?
	1. Productus shales.	1. Productus shales.	1. Productus shales. Permian.

III.—GENERAL DEVELOPMENT OF THE HIMALAYAN TRIAS.

A broad sedimentary belt extends from Kashmir through Spiti, Garhwal and Kumaon to the N.-W. boundary of Nepal.

In this sedimentary zone of fossiliferous deposits, which range from Middle Cambrian to Cretaceous, the Trias is developed in a facies of dark shales and limestones of exclusively marine origin. No igneous rocks have been noticed within the Triassic or Jurassic series. The limestones are of dark or grey colour, well bedded as a rule, and in some horizons either concretionary or dolomitic. In the majority of sections there is a remarkable contrast between the light grey dolomitic limestones of the upper and the dark coloured shales and limestones of the lower portion of the Triassic rocks, the total thickness of which amounts to more than 4,000 feet in Spiti.

This normal development of the Himálayan Trias is chiefly characterised by the regular distribution of each single horizon over a comparatively large area, and by the absence of a facies of red marble.

In the region of the exotic blocks in Malla Johar and near Chitichun No. I, the Triassic strata show a development differing considerably from that observed in the normal sections of the main region of the Himálayas. In this region the Triassic system is of only comparatively small thickness, and most of the Triassic horizons are developed in a facies of red limestone and marble exhibiting a striking resemblance to the Hallstatt limestone of the Eastern Alps. Especially in the beds of the Carnic stage are there remarkable agreements with their homotaxial equivalents in the Mediterranean region, the agreement being faunistic as well as lithological.

Thus two regions of different development can be distinguished within the area of Triassic rocks in the Central Himálayas, one of them representing the normal facies of the Mesozoic belt, and the other representing the facies of exotic blocks connected intimately with igneous intrusions.

The former A. v. Krafft termed the Himálayan and the latter the Tibetan *facies* of the marine Trias.

A. Himalayan Facies.

I. THE LOWER TRIAS.

a. Spiti.

The most complete section of the marine lower Trias is found in Spiti, although in thickness it is inferior to that of Painkhanda and Byans.

Lower Triassic fossils were known from the Himálayas as far back as 1865, when C. W. Guembel¹ recognised in the collections of the brothers von Schlagintweit several species of bivalves, which he identified with *Anodontophora fassaensis* Wissm., *Lima costata* Muenst., *Nucula Goldfussi* Alb. from the Werfen beds of the Eastern Alps. The locality from which those fossils are quoted is Balamsali near Dankhar. The identity of this locality with a place near Lilang in Spiti is very doubtful, as will be shown below.

Stoliczka failed to recognise the existence of lower Triassic rocks in Spiti. The credit of their discovery *in situ* is due to C. L. Griesbach. He found the lowest beds, following immediately above the Permian *Productus*, or Kuling, shales to contain the fauna of the *Otoceras* beds, discovered by him in 1879 in the Painkhanda sections near the Niti pass.

He also recognised that a second higher division was present in the Lower Triassic section of Muth, although he did not separate the two horizons distinctly.

The Spiti sections were studied in great detail by H. Hayden and A. v. Krafft in 1899. On their researches and on the examination by Diener of their rich collections the following statements are based.

The best exposures of lower Triassic rocks have been observed in a section near Lilang. The sequence² is as follows, in descending order :—

¹ C. W. Guembel : Ueber das Vorkommen von unteren Triassschichten in Hochasien, nach den von den Gebruedern Schlagintweit gesammelten Fossilstuecken beurteilt. *Sitzgsber. kgl. bayr. Akad.*, Muenchen, 1865, Pt. 2, p. 348.

² Described in *General Report Geol. Surv. of India* for 1899-1900, p. 200, and in H. Hayden, *Geology of Spiti, l. c.*, pp. 63-67.

			Ft.	In.	
11. Nodular limestone.	.	.	60	0;	(Niti limestone, Noetling).
10. Calcareous shales	.	.	6	0;	containing <i>Rhynchonella Griesbachi</i> Bittn.
9. Shaly limestone					; containing <i>Pseudomonotis himaica</i> Bittn.
8. Grey shaly limestones and grey shales, alternating very regularly.			24	0;	unfossiliferous.
7. Nodular limestone with thin shaly partings.		very	5	7;	with <i>Hedenstrœmia Mojsisovicsi</i> , <i>Xenodiscus nivalis</i> , <i>Pseudosagceras multilobatum</i> .
6. Grey shaly limestones	.	.	0	7;	} poor in fossils. No determinable ammonites.
5. Shales	.	.	0	10;	
4. Concretionary limestones and shales.		and	3	0;	very rich in <i>Meekoceras</i> , especially <i>M. lilangense</i> and <i>M. Varaha</i> .
3. Grey limestones	.	.	1	5;	containing <i>Ophiceras Sakuntala</i> and <i>Pseudomonotis Griesbachi</i> .
2. Sandy limestones weathering brown.			1	7;	no fossils.
1. Rusty brown, ferruginous limestone.			0	5;	<i>Ophiceras div. sp.</i> , <i>Otoceras sp.</i>

Productus, or Kuling shales.

In this, as in several other sections, the band of grey shaly limestones and shales (5 and 6), from which no determinable ammonites have been obtained, marks a lithological as well as a faunistic boundary between a lower and an upper division of the sequence of beds which are exposed between the Permian Productus shales and the nodular limestone of the Muschelkalk.

This boundary is marked even more strongly in the section S. E. of Muth, because the bands 5 and 6 there reach a thickness of four feet and are entirely unfossiliferous, whereas the ammonites restricted to bed 7 in the Lilang section occur throughout the entire series of thin-bedded grey shales and limestones (8) in the hills S. E. of Muth.

It has therefore been found convenient to divide the lower Trias of Spiti into two divisions, the lower of these comprising beds 1 to 4 and reaching an entire thickness of 6 feet 5 inches only, the upper comprising beds 6 to 10 and attaining a thickness of 35 feet 7 inches in the Lilang section.

The genus *Otoceras* Griesb. is restricted to the rusty brown ferruginous limestone at the very base of the series. Even here it is very rare,

In the large collections which were made by H. Hayden and A. v. Krafft, the following species are represented :—

- Otoceras Woodwardi* Griesb. (Khar, 5 miles S. of Ensa, S. E. of Muth, Kuling).
- „ *cf. undatum* Griesb. (5 miles S. of Ensa).
- „ *Clivei* Dien. (5 miles S. of Ensa, S. E. of Muth, S. W. of Gaichund).
- „ *nov. sp. ind. aff. Clivei* Dien. (S. W. of Gaichund).

They occur together with *Episageceras Dalailamae* Dien., *Prospingites nala* Dien. and several species of *Ophiceras*, especially *O. Sakuntala* Dien., which is also the most frequent companion of the genus *Otoceras* in the corresponding beds of Painkhanda.

From the higher beds of the lower Trias of Spiti *Otoceras* is completely absent.

The next fossiliferous horizon is bed 3. Both *Ophiceras* and *Pseudomonotis Griesbachi*—a representative of the Alpine group of *Claraia*—are very common. The genus *Ophiceras* Griesb. is represented by the following species :—

- Ophiceras Sakuntala* Dien.
- „ *tibeticum* Griesb.
- „ *cf. demissum* Opp.
- „ *Chamunda* Dien.

Xenodiscus radians Waag. also occurs in this main layer of *Ophiceras*, whereas the presence of *Meekoceras*, although quoted by A. v. Krafft (General Report Geol. Surv. of India for 1899-1900, p. 200) and Hayden (Geology of Spiti. I. c., pp. 63, 65), cannot yet be considered as beyond dispute.

Whereas in bed 3 *Ophiceras* is the predominating genus, it is extremely rare in bed 4, being represented there by a single species only (*Ophiceras obtuso-angulatum* Dien.). Its place is taken by the genus *Meekoceras*. Including the two subgenera *Aspidites* and *Koninckites*, not less than fourteen species are present, namely :—

- Meekoceras Varaha* Dien.
- „ *Markhami* Dien.
- „ *lilangense* Krafft.
- „ *lingtiense* Krafft.
- „ *tenuistriatum* Krafft

- Meekoceras rugosum* Krafft.
 „ *jolinkense* Krafft.
 „ *disciforme* Krafft.
 „ *cf. discus* Waag.
Aspidites spitiensis Krafft.
 „ *ensanus* Krafft.
 „ *crassus* Krafft.
Koninckites Haydeni Krafft.
 „ *alterammonoides* Krafft.

To those species of ammonites must be added :—

- Xenodiscus radians* Waag.
 „ *lilangensis* v. Krafft.

Hedenstrœmia lilangensis v. Krafft, the most primitive species of this genus, together with a new genus, nearly allied to *Hedenstrœmia*, but holding a position intermediate between it and *Pseudosageceras* in the arrangement of its sutural line.

Of *Nautiloidea* one species only—*Grypoceras lilangense* Krafft—is at present known.

Lithologically the *Ophiceras* beds and the *Meekoceras* beds are connected so intimately, that A. v. Krafft and H. Hayden did not succeed in keeping separate the fossils which they collected in some of their detailed sections. Those two faunistic subdivisions should therefore not be taken as sharply defined stratigraphical horizons of paramount importance. The two faunæ are, it is true, as a whole distinct, but it must be understood that we cannot yet say anything definite about their affinities, the original layer of a considerable number of species, which are perhaps common to both of them, remaining uncertain.¹

¹ There are not less than thirteen species of doubtful stratigraphical position, namely :—

<i>Meekoceras boreale</i> Dien.	<i>Xenodiscus rigidus</i> Dien.
„ <i>cf. radiosum</i> Waag.	„ <i>rotula</i> Waag.
„ <i>dubium</i> Krafft.	„ <i>cf. plicatus</i> Waag.
„ <i>kyokticum</i> Krafft.	<i>Nannites hindostanus</i> Dien.
<i>Aspidites Vidarbha</i> Dien.	„ <i>Herberti</i> Dien.
<i>Proptychites typicus</i> Krafft.	<i>Flemingites Guyerdeli</i> Dien.
„ <i>sp. ind. aff. typico.</i>	

All of these certainly belong to the lower division of the Lower Trias, but the particular horizon in which they have their habitat, is not known.

Thus from a faunistic point of view we can distinguish three subdivisions in the lower portion of the Lower Trias of Spiti, namely, the *Otoceras* bed (1), the *Ophiceras* bed (3), the *Meekoceras* bed (4), each of them being characterised by the abundance—but not, as a rule, the exclusive occurrence—of one genus of ammonite, which predominates in that particular horizon.

Beds 7 and 8, which are separated in all sections studied by Hayden and A. v. Krafft, by a band of unfossiliferous rock from 1½ to 4 feet in thickness from the lower division (*Meekoceras* bed), contain a fauna of uniform character, in which some species of *Xenodiscus* (especially *X. nivalis* Dien.), *Hedenstroemia* and *Flemingites* predominate. For this horizon the name of “Hedenstroemia beds” or “Zone of *Flemingites Rohilla*” has been proposed by A. v. Krafft. A rich fauna of this horizon was first discovered by C. L. Griesbach in 1883 S. E. of the village of Muth, and its stratigraphical independence was recognised by Diener in 1895.

The fauna of the Hedenstroemia beds of Spiti comprises the following species of Cephalopoda :—

- Pleuromutilus Dieneri* Krafft.
- Meekoceras pseudoplanulatum* Krafft.
- „ *sp. ind. aff. pilato* Hyatt et Smith.
- „ *cf. joharenses* Krafft.
- „ *solitarium* Krafft.
- Aspidites Muthianus* Krafft.
- „ *superbiformis* Dien.
- „ *nov. sp. ind. aff. superbo* Waag.
- Koninckites Yudishthira* Dien.
- „ *giganteus* Krafft.
- Xenodiscus Kapili* Dien.
- „ *Purusha* Dien.
- „ *nivalis* Dien.
- „ *nov. sp. ind. ex. aff. nivalis*.
- „ *cf. trapezoidalis* Waag.
- „ *asiaticus* Krafft.
- Flemingites Rohilla* Dien.
- „ *Muthensis* Krafft.
- „ *Griesbachi* Krafft.

- Flemingites Salya* Dien.
 „ *sp. ind. ex. aff. Salya.*
 „ *nov. sp. ind.*
Ceratites pumilio Krafft.
Prionites nov. sp. ind.
Tirolites injucundus Krafft.
Nannites hindostanus Dien.
 „ *medius* Dien.
Pseudosageceras multilobatum Noetl.
Hedenstrœmia Mojsisovicsi Dien.
 „ *muthiana* Krafft.
Sibirites spitiensis Krafft.

There is only one single species, *Nannites hindostanus* Dien., which connects the faunæ of the Hedenstrœmia beds and of the lower division of the Lower Trias. Otherwise the two are separated much more distinctly than those of the Meekoceras and Ophiceras beds.

The presence of the first true *Ceratites*, of numerous species of *Flemingites*, of *Hedenstrœmia* with sutures far more advanced than in *H. lilangensis*, of species of *Aspidites* and *Koninckites* of large size and with complicated sutures, imparts to the fauna of the Hedenstrœmia beds its peculiar aspect.

On the top of the Hedenstrœmia beds there follow lithologically similar beds of shales and limestones having a thickness of about 6 feet. Two fossiliferous horizons were discovered in those beds by H. Hayden. The lower horizon has yielded large numbers of bivalves, chiefly *Pseudomonotis himaica* Bittn. and *Ps. decidens* Bittn. The upper horizon with *Rhynchonella Griesbachi* Bittn., and *Rh. himaica* Bittn., corresponds to a layer, which in Painkhanda has been included in the lower Muschelkalk by Griesbach and Diener.

b. Painkhanda.

Our knowledge of the development of the Lower Trias in Painkhanda has been derived chiefly from the examination of the classical section of the Shalshal cliff near Rimkin Païar by C. L. Griesbach, C. Diener and F. Noetling.

In 1879 the *Otoceras* fauna was discovered by C. L. Griesbach on the top of the Permian Productus shales. The bed containing this fauna was

considered by him as a passage bed, whereas all the beds of dark limestone and shale following above, up to the earthy limestone with *Rhynchonella Griesbachi* Bittn., amounting to 51 feet in thickness, were assigned to the Lower Trias.

In 1892 a second fossiliferous horizon was discovered by Diener in the upper division of this rock group, not far below the lower limit of the earthy limestone with *Rhynchonella Griesbachi*. In 1900 F. Noetling discovered a third fossiliferous bed in the lower division of the Lower Trias about 21 feet above the top of the Kuling (Productus) shales.

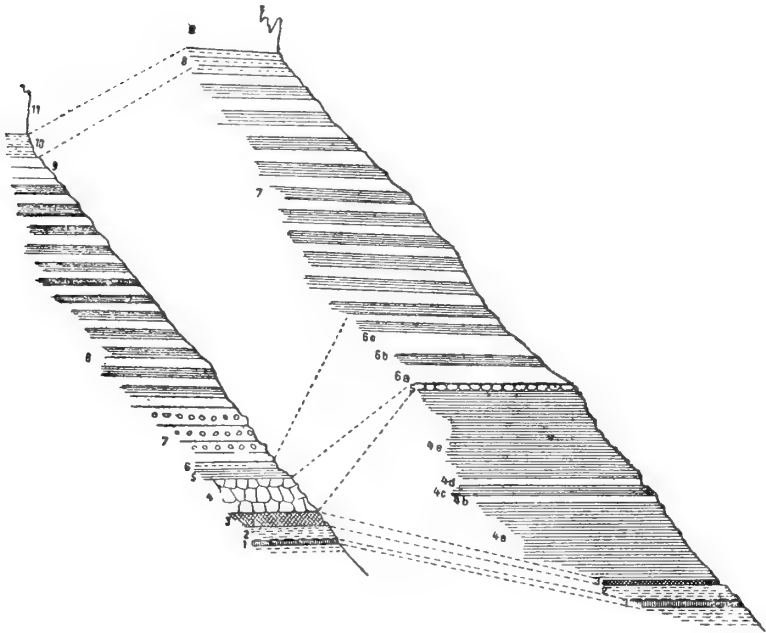


FIG. 1.—Detailed sections through the Lower Trias near Lilang (left) and of the Shalshal cliff (right).

Figures corresponding to the text on pp. 16 and 22.

Although the correlation of those horizons has been the subject of many discussions, the learned authors who have examined the section of the Shalshal cliff, agree entirely regarding the actual sequence of the Lower Triassic beds. According to Noetling's¹ and Diener's observations, this sequence is as follows, in descending order² :—

9. Hard, splintery, nodular limestone (Niti limestone) 60 feet.
8. Earthy, grey limestone, shaly near base, with *Rhynchonella Griesbachi* and *Sibirites Prahlada* : 3 ft.
7. Thin-bedded, grey limestone, with regular partings of shale, containing *Flemingites Rohilla* and *Pseudomonotis himaica* near top : 25 ft.
6. Grey limestone, divided into two bands by a shaly parting. No determinable fossils : 5 ft.
5. Dark concretionary limestone, containing the main-layer of *Meekoceras Markhami* and *M. Varaha* : 8 ins.
4. Dark-blue shales, separated by a band of grey limestone. Unfossiliferous : 18 ft.
3. Dark blue limestone, with *Otoceras Woodwardi* and *Ophiceras tibeticum* : 5 ins.
2. Dark hard clay, with limestone concretions, containing very few fossils (*Episagoceras Dalailamæ*, *Proptychites Scheibleri*) : 1½ ft.
1. Dark-blue limestone, main-layer of *Otoceras Woodwardi* and *Ophiceras Sakuntala*. Near top very rich in *Pseudomonotis Griesbachi* : 1 ft.

Productus or Kuling shales. Dark, thin-bedded shales, with partings of concretionary limestone.

Of the section of Kiunglung, *e.g.*, on the southern slope of the Niti pass, our knowledge is less complete.

¹ F. Noetling : Ueber das Alter der Otocerasschichten von Rimkin Paiar (Painkhanda) im Himálaya. *Neues Jahrb. f. Miner., etc.*, Beilagebd, XVIII, 1904, p. 541 ; *Lethæa mesozoica* Bd. I. Asiatische Trias, 1905, pp. 128, 149.

² Noetling's measurements, as given on pages 541 and 544 of his memoir on the age of the Otoceras beds of Rimkin Paiar, do not agree. On p. 541 the thickness of unfossiliferous beds between beds 3 and 5 is estimated at 10 feet, whereas it is estimated (more correctly) at 6 metres on page 544. The thickness of the Hedenstræmia beds is given as 20 feet on p. 341, whereas it is estimated at 10 or 12 metres on p. 149 of the *Lethæa mesozoica* (Asiatische Trias, l. c.). The higher figures agree better with Griesbach's and my own measurements.

Bed 1 is the main layer of *Otoceras Woodwardi* Griesb., which is, however, far inferior to *O. Sakuntala* in number of individuals. From bed 2 two specimens of ammonites only are known to me. Both were collected by myself in 1892. There is no specimen from this bed either in Noetling's or in A. v. Krafft's collections. My species are :—

Episageceras Dalailamæ Dien.

Proptychites Scheibleri Dien.

Of the first species a fragment has also been discovered in bed 1, the main layer of the genus *Otoceras*.

In bed 3 *Ophiceras tibeticum*, which occurs also in bed 1, still persists together with the genus *Otoceras*, which is, however, rare and represented there by a variety of *O. Woodwardi*.

Those three beds, with their uniform fauna, can therefore be united in one single division, to which the name of "*Otoceras* beds," as proposed in 1879 by C. L. Griesbach, has been restricted by Noetling.

The fauna occurring in the *Otoceras* beds of Painkhanda is composed of the following species of Cephalopoda :

Grypoceras brahmanicum Griesb.

Episageceras Dalailamæ Dien.

Otoceras Woodwardi Griesb.

„ *undatum* Griesb.

„ *Clivei* Dien.

„ *Draupadi* Dien.

„ *fissisellatum* Dien.

„ *Parbati* Dien.

Hungarites sp. ind.

Ophiceras Sakuntala Dien.

„ *tibeticum* Griesb.

„ *medium* Griesb.

„ *gibbosum* Griesb.

„ *demissum* Opp.

„ *ptychodes* Dien.

„ *serpentinum* Dien.

„ *stricturatum* Frech et Noetl.

Meekoceras Hodgsoni Dien.

Proptychites Scheibleri Dien.

Prosphingites Kama Dien.

„ *nala* Dien.

Xenodiscus himalayanus Griesb.

Vishnuites Pralambha Dien.

On the top of bed 1, *Pseudomonotis* (*Claraia*) *Griesbachii* Bittn. is most common, but not restricted to this bed exclusively.

Bed 5, which is separated from the topmost fossiliferous bed of the *Otoceras* stage by a mass of dark blue shales with limestone partings, 18 feet in thickness, contains the *Meekoceras*-fauna, discovered by Noetling in 1900.

It is less rich in species than in the Spiti sections, the commonest types being *Meekoceras Markhami* Dien. and *M. Varaha* Dien. Besides these we have to enumerate :—

Meekoceras shalshalense Krafft.

Aspidites spitiensis Krafft.

and with great probability at least, *Meekoceras boreale* Dien., and, according to Noetling (*Lethæa mesozoica*, l. c., p. 149), *Meekoceras cf. radiosum* Waag. and *M. cf. discus* Waag.

Ophiceras tibeticum Griesb. probably also ranges from the *Otoceras* stage into the *Meekoceras* beds. One of Griesbach's specimens from the Shalshal cliff is marked bed 70 (25 feet above the layer of *Otoceras Woodwardi*). This is approximately the position of the fossiliferous layer of the *Meekoceras* beds. There is no valid reason for questioning the accuracy of Griesbach's statement.

The lithological boundary between the lower and upper divisions of the Lower Trias in Painkhanda passes just along the top of the concretionary limestone containing the *Meekoceras*-fauna. The lowest bands of grey limestone (bed 6) are very poor in fossils, but such occur throughout the entire thickness of the higher beds (7), which consist of light grey limestones, 4 to 6 inches in thickness, and alternating very regularly with shales of less or equal thickness. The fauna is, however, less rich in species than in the corresponding beds of Spiti, in the

sections S. E. of Muth. The following Cephalopoda have been collected by Griesbach and Diener¹:—

Pleuromutilus Dieneri Krafft.

Xenodiscus nivalis Dien.

„ *Purusha* Dien.

Flemingites Rohilla Dien.

Proavites Sisupala Dien.

Pseudomonotis himaica Bittn. and *Ps. decidens* Bittn. have also been quoted from bed 7 by Bittner, but their exact layer has not been ascertained. We do not know if they are distributed throughout the entire thickness of this subdivision or restricted to its topmost bed, as in the section at Lilang in Spiti.

For this upper division of the Lower Trias in Painkhanda the name “Subrobustus beds” was proposed by Diener in 1895, because he considered his type-specimen of *Ceratites subrobustus* (= *Keyserlingites Dieneri* Mojs.) to have been derived from its topmost layers, in which *Flemingites Rohilla* is the chief leading fossil. But this specimen was probably extracted from a detached block of the overlying Muschelkalk, since H. Hayden and A. v. Krafft have obtained numerous examples of *Keyserlingites (Durgaites) Dieneri* and its allies from the Muschelkalk, but not a single specimen from the Lower Trias. In the face of such convincing evidence we are justified in claiming the Indian group of *Ceratites subrobusti (Durgaites)* as a subgenus of Muschelkalk, not of Lower Triassic, age.

The name “Subrobustus beds” must consequently be discarded and replaced by the name “Hedenstrœmia beds,” which was introduced for this rock-group (horizon of *Flemingites Rohilla*) by A. v. Krafft.

c. Eastern Johar.

The presence of marine sediments of Lower Triassic age in Eastern Johar has been recorded by C. L. Griesbach and by T. D. La Touche in several sections of the Dharma and Lissar valleys.

¹ To this list *Hedenstrœmia Mojsisovicsi* Dien. has been added by Noetling (*Lethæa mesozoica*, l. c., p. 149), but the specimens have not been found among the Lower Triassic materials belonging to the Geological Survey.

The Lower Trias seems to be developed in a facies of dark limestones and shales in the lower, and of light grey limestones in the upper, division. In the Lissar valley this group reaches an entire thickness of 80 to 100 feet, according to Griesbach (Central Himálayas, l. c., p. 175).

Palæontologically those two divisions are well characterised by two different associations of fossils, which can be easily distinguished among the collections of those two learned authors, which were made on the crest of a ridge separating the Lissar and Dharma valleys. The presence of the lower division, including equivalents of the *Otoceras* and *Meekoceras* beds, is clearly proved by the following species :—

Pseudomonotis (Claraia) Griesbachi Bittn.

Xenodiscus himalayanus Griesb.

„ *cf. rotula* Waag.

Ophiceras Sakuntala Dien.

Proptychites typicus Krafft.

Meekoceras boreale Dien.

„ *dubium* Krafft.

Aspidites Vidarbha Dien.

The upper division of the Lower Trias (*Hedenstroemia* beds) is indicated by *Xenodiscus Purusha* Dien.

d. Byans.

The Lower Trias of Byans differs considerably from that of Johar, Painkhanda and Spiti.

According to the notes of F. H. Smith (1899) and A. v. Krafft (1900), it is represented by a mass of chocolate limestone attaining about 150 feet in thickness. This limestone passes by interstratification into the underlying *Productus*, or Kuling, shales. No fossils have been found in those passage-beds by Smith, but near the base of the compact, chocolate-coloured limestone both A. v. Krafft and F. H. Smith have collected numerous fossils in a sandy rock near Jolinka and Kuti. They point distinctly to the lower division of the Lower Trias.

One species, *Ophiceras cf. serpentinum* Dien., is characteristic of the *Otoceras* stage. The rest are chiefly elements of the *Meekoceras* fauna, namely :—

Meekoceras boreale Dien.

„ *dubium* Krafft.

Meekoceras jolinkense Krafft.

Aspidites spitiensis Krafft.

„ *Vidarbha* Dien.

Proptychites typicus Krafft.

Xenodiscus radians Waag.

„ *rotula* Waag.

The presence of the upper division of the Lower Trias in the chocolate limestone of Kalapani, Lilinithi, Jolinka and Kuti is indicated by the following species of ammonites :—

Flemingites cf. Griesbachi Krafft.

Hedenstræmia Mojsisovicsi Dien.

„ *acuta* Krafft.

From Jolinka only the following species of *Sibirites* are known :—

Sibrites spiniger Krafft.

„ *robustus* Krafft.

„ *sp. ind. aff. robusto*.

„ *stephanitiformis* Krafft.

Together with a considerable number of new species of this genus which are too badly preserved to permit of specific determination.

In the fauna of Jolinka a peculiar element is represented by the genus *Sibirites*, which is comparatively rich in species and was regarded by the late Dr. A. v. Krafft as indicative of a special palæontological horizon.

e. Kashmir.

Lower Trias was not until recently known with certainty from any part of Kashmir, but A. v. Krafft insisted that it was represented there for the following reasons¹ :—

Among the Triassic fossil material sent to him for description, A. Bittner discovered several specimens of a *Myophoria*, which belongs to the group of *M. ovata* of the Alpine Werfen beds (*Myophoria sp. ind. ex aff. ovatæ* Goldfuss).² The specimens had been collected by Stoliczka in

A. v. Krafft : Zur unteren Trias von Spiti. *Centralblatt f. Mineral.*, etc., 1901, pp. 197-199.

² A. Bittner : *Palæontologia Indica*, ser. XV, Vol. III, pt. 2, p. 67.

the Dras valley, and originally determined by him as *Megalodon columbella*.¹

According to Bittner, they are imbedded in an impure calcareo-arenaceous rock, and he suggests that the specimens may belong to the same horizon—or one nearly related to it—as those bivalves which had been described in 1865 by C. W. Guembel from the collections of the brothers Schlagintweit.² Those bivalves proved in part identical with species from the Alpine Werfen beds, and were imbedded in a shaly, micaceous, very dense, yellow-grey, calcareous sandstone, resembling “Grauwacke,” which, according to Guembel, is scarcely distinguishable from certain layers of the Alpine Werfen beds.

A. v. Krafft lays special stress on the fact that in the Himálayas, as far as they have been surveyed, the Lower Trias has always been found to consist of limestones with Cephalopoda and bivalves, intercalated with shales, but that sandstones have been observed nowhere. This is also the case at Lilang, only a few miles from Dankhar, the locality at which the Schlagintweit fossils are reported to have been found. A. v. Krafft therefore peremptorily emphasizes the fact that sandstones are entirely absent from the Lower Trias of Spiti.

When visiting Spiti in 1899, he endeavoured, but in vain, to clear up the evident discrepancy existing between the actual facts and Guembel's record.

On inquiry of several natives of Dankhar and the neighbourhood as to the existence of a village of the name Balamsali, he invariably received the answer that no village of that name was known. Nor could he find in the sections near Dankhar any support for Guembel's statement.

The Lower Trias is—with the Muschelkalk—cut out near Dankhar by a big fault running parallel to the Spiti valley. He searched in the few rivulets, in which sections are exposed, but observed in one locality only a thin wedge of black limestone with Cephalopoda, belonging to the Lower Trias and compressed between the Permian Productus shales and a limestone mass of ladinic or carnic age, which had been pushed by a fault over this wedge.

¹ F. Stoliczka : *Memoirs, Geol. Surv. of India*, V, p. 349.

² *Sitzungsber. kgl. Akad. d. Wissensch. Muenchen*, 1865, II, p. 348.

The rocks in the neighbourhood of Dankhar are therefore of such a character, that the sandstones with Werfen types cannot have possibly come from there. Moreover no village of the name Balamsali is known.

A. v. Krafft thinks that on the labels accompanying the specimens collected by the brothers Schlagintweit, the localities have been confused. In this opinion he is supported by the fact that not infrequently the localities of specimens collected by those travellers are not known exactly, and that in one other instance localities must needs have been confused.

This is the case of a specimen of *Ceratites Voiti* Opp. (coll. Schlagintweit) described by Diener (Muschelkalk Cephalopoda, l. c., p. 9), which was said to have come from the Kunzum pass in Spiti. Both H. Hayden and A. v. Krafft have traversed the Kunzum pass (leading from Losar in the Spiti valley to the Chandra valley), and have found it built up chiefly of Haimantas. The nearest locality, where Muschelkalk occurs, is situated about ten miles to the N.E. of the Kunzum pass, on the left bank of the Spiti river. Thus there can be hardly any room for doubt that the brothers Schlagintweit collected their fossils of Werfen facies somewhere else, far away from Dankhar in Spiti. Probably those fossils may have come from a layer similar to that in which *Myophoria* sp. ind. ex. aff. *ovata* was found by Stoliczka.

I feel, however, obliged to remark that species belonging to the group of *Myophoria ovata* Goldf. are not restricted to the Alpine Werfen beds, but range also into the Muschelkalk, and that there is, consequently, no convincing proof of the Lower Triassic age of the beds discovered by Stoliczka in the valley of the Dras river.

F. Noetling¹ also claims the discovery of Lower Triassic beds in Kashmir. "Near Pastuni, three days' march from Srinagar"—he writes—"I collected a faunula of Cephalopoda in a hard dark blue limestone. They have not yet been examined, but from a preliminary comparison with other Himálayan faunæ it was soon evident that they could neither represent Muschelkalk nor Upper Trias. There exists great probability of their Lower Triassic age. We may, perhaps, consider them as an equivalent of the Hedenstrœmia beds."

¹ F. Noetling : Asiatische Trias, *Lethæa mesozoica*, I. c., p. 172.

F. Frech¹ infers the presence of beds of Lower Triassic age in Ladakh from a new examination of *Ammonites peregrinus* Beyr. in the Museum of Berlin. The specimen had been collected by the missionary Prochnow and described by E. Beyrich in 1864 and 1867.² From the illustrations and descriptions I did not dare to decide whether the poorly preserved fragment belonged to an ammonite of Muschelkalk or Lower Triassic or even Permian age.³ Frech, however, on the strength of a personal examination, includes it in the genus *Flemingites* Waag., thus proving the presence of the Hedenstrœmia stage.

The recent researches of Hayden⁴ and Middlemiss⁵ in the Vihi district have done much to ascertain the wide distribution of Lower Triassic sediments in Kashmir.

Hayden was fortunate enough to discover a fossiliferous horizon in the Guryul ravine, containing *Pseudomonotis*, *Bellerophon*, *Xenodiscus*, *Flemingites*. The sections in the Guryul ravine and east of it have been examined in detail by C. S. Middlemiss (l. c., p. 303). He found the beds, which seem to be included in the Lower Trias. of unusual thickness (about 150 feet). The lower division of hard, thin-bedded limestones (about 100 feet) has not yielded any fossils, but in the upper division consisting of shales with thin limestone beds intercalated, several fossiliferous horizons have been noticed. Among the species of Cephalopoda enumerated by Middlemiss, *Meekoceras cf. lilangense* Krafft points to the Meekoceras stage, whereas *Xenodiscus* of the group of *X. Purusha* and the sharp-keeled ammonites recalling *Hedenstrœmia* suggest the presence of a younger (Hedenstrœmia) stage. Equivalents of the lowest (Otoceras) stage have not as yet been found in Kashmir.

f. Interregional Correlation of fossiliferous horizons.

The development of the Lower Trias is almost identical in Painkhanda and Spiti. The two sections of the Shalshal cliff and of Lilang

¹ F. Frech : Triasammoniten aus Kashmir, *Centralbl. f. Miner.*, etc., 1902, p. 134.

² E. Beyrich : *Monatsber. Kgl. Akad. d. Wissensch. Berlin*, 18 January 1864, p. 58, and "Ueber einige Cephalopoden aus dem Muschelkalk der Alpen, etc.," *Abhand. kgl. preuss. Akad. Berlin*, 1866, No. 2, p. 123, Taf. V, fig. 4.

³ Cephalopoda of the Lower Trias, *Palæont. Ind.*, l. c., p. 1.

⁴ Records, *Geol. Surv. of India*, XXXVI, (1907), p. 23.

⁵ C. S. Middlemiss : Gondwanas and related marine sedimentary systems of Kashmir. *Records, Geol. Surv. of India*, XXXVII, (1909), p. 297.

agree very closely, although their distance apart is 130 miles. The Lower Trias in both districts consists of dark limestones alternating with shales. In the lower division, following above the Permian Kuling, or *Productus*, shales, black limestones predominate. In the upper division the limestones are of a dark grey colour and thin-bedded. In Spiti the upper division is of considerably greater thickness than the lower one, 30 feet to 6 feet, whereas in the Shalshal cliff this proportion is only 30 feet to 21 feet. The lithological boundary, although not very sharp, is well marked both in the sections of Painkhanda and of Spiti.

The lower division contains three fossiliferous horizons in Spiti and four in Painkhanda, but in both regions the topmost horizon only has yielded a fauna which is distinguished from that of the lower horizons. The lower horizons represent the *Otoceras* beds *sensu stricto*.

In 1901 two different zones were distinguished in the *Otoceras* beds of Painkhanda by Noetling,¹ the lower containing the fauna of *Otoceras Woodwardi*, the upper being characterised by the predominance of *Ophiceras tibeticum*. In 1904 a third zone was added to them by Noetling,² who consequently distinguished among the *Otoceras* beds the following three zones :—

3. Zone of *Ophiceras tibeticum* Griesb.
2. „ „ *Episageceras Dalailamæ* Dien.
1. „ „ *Otoceras Woodwardi* Griesb.

Noetling's statement that those "three zones are sharply separated faunistically" is contradictory to the facts, as I have tried to show in my memoir on the stratigraphical position of the *Otoceras* beds.³ A distinction of separate palæontological zones in the uniform fauna of the *Otoceras* stage is purely artificial. There is no element in the fauna of either horizon which might justify its palæontological independence from the others. They are minute local subdivisions of one single zone only.

Those local subdivisions can also be recognised in the section of Lilang, Spiti, although their faunæ do not correspond exactly. The

¹ F. Noetling in *Lethæa palæozoica*, Vol. II. Dyas, p. 656.

² F. Noetling, *Neues Jahrb. f. Min.*, Beil. Bd. XVIII, 1904, and *Lethæa mes.*, Asiatische Trias, l. c., p. 132.

³ C. Diener : Ueber die stratigraphische Stellung der *Otoceras* beds des Himalaya, *Centrbl. f. Min.*, 1905, p. 2.

main layer of *Otoceras Woodwardi* in the Shalshal cliff agrees with the rusty-brown, ferruginous layer at the base of the Triassic series in the Lilang section, to which the genus *Otoceras* is restricted in Spiti. The place of the hard, dark clay with *Episageceras Dalailamæ* is taken by the unfossiliferous sandy limestone (bed 2) of Lilang. The main layer of *Ophiceras* in Spiti corresponds to the bed containing *Ophiceras tibeticum* in the Painkhanda sections.

The vertical distribution of *Otoceras* is smaller in Spiti than in Painkhanda. The absence of this genus in the second fossiliferous horizon of the sections near Lilang justifies the distinction of an *Otoceras* bed and an *Ophiceras* bed, as advocated by A. v. Krafft,¹ but it is no valid reason for dividing the fauna of the *Otoceras* stage into two separate palæontological zones, since the predominating types of *Ophiceras* persist throughout the two horizons and impart to the fauna a uniform aspect.

Thus the fauna of the *Otoceras* stage represents one single palæontological zone only, which, from its most conspicuous types, should be called zone of *Otoceras Woodwardi* and *Ophiceras Sakuntala*.

The second fauna of Lower Triassic age, which represents a special stratigraphical horizon, is the fauna of the Meekoceras beds.

In the section of Lilang it follows immediately above the *Ophiceras* bed and is only three feet in thickness. In Painkhanda it is separated from the bed with *Ophiceras tibeticum* by a large mass of unfossiliferous rock.

The following detailed section has been published by Noetling (Asiatische Trias, l. c., pp. 129, 130):—

5.	Dark, concretionary limestone, with <i>Meekoceras</i>	
	<i>Markhami</i> Dien.	cm. 20
4e.	Dark blue shales	2m. 80
4d.	Hard, grey limestone	17
4c.	Dark blue shales	25
4b.	Hard, grey limestone	30
4a.	Dark blue shales	2m. 50
3.	Hard, blue, very tough limestone, with <i>Ophiceras</i>	
	<i>tibeticum</i> Griesb.	12

In the section of the Shalshal cliff the Meekoceras fauna makes its appearance only nineteen feet above the top of the *Otoceras* beds, but it

¹ A. v. Krafft: *Gen. Report, Geol. Surv. of India*, 1900-01, p. 4.

agrees entirely with that of Spiti and is also contained in a concretionary limestone of dark blue colour.

The direct superposition of the *Meekoceras* horizon above the *Ophiceras* bed in Spiti has often rendered an exact separation of their faunæ *in situ* very difficult or even impossible. They are certainly linked together by a number of species common to both of them. Neither is *Meekoceras* entirely absent in the lower horizon nor *Ophiceras* in the upper one. In Spiti *Meekoceras Varaha* and *M. lilangense* are the commonest species, whereas in Painkhanda *M. Markhami* predominates. In Spiti the *Otoceras* stage is poor in species, compared with the rich fauna of the *Otoceras* beds in Painkhanda, but the *Meekoceras* fauna is more richly developed in the Spiti sections.

Throughout the upper division of the Lower Trias in Painkhanda and Spiti a single and uniform fauna only has been found. This is the fauna of the *Hedenstrœmia* beds or the zone of *Flemingites Rohilla*. It differs considerably from that of the *Meekoceras* beds. The genus *Meekoceras* is chiefly represented by large species belonging to the subgenera *Aspidites* and *Koninckites*. *Xenodiscus*, *Flemingites* and *Hedenstrœmia* have reached their maximal development.

In the topmost beds of the *Hedenstrœmia* stage of Spiti a bivalve facies, with *Pseudomonotis himaica* Bittn. as leading fossil, makes its appearance, but the stratigraphical independence of this bivalve limestone as a distinctly marked palæontological horizon is very doubtful.

The fourth and youngest fauna of Lower Triassic age is hitherto known from one locality in Byans only.

A small faunula collected by F. H. Smith near Jolinka has been attributed by A. v. Krafft to a stratigraphically well defined bed, not far from the top of the chocolate limestone. It represents the zone of *Sibirites spiniger* and consists exclusively of species of the genus *Sibirites*, which is restricted to the upper Ceratite limestone of the Salt Range.

Sibirites spitiensis in the section of Muth is perhaps indicative of a representation of this palæontological zone in the *Hedenstrœmia* beds of Spiti.

g. Correlation with the Ceratite beds of the Salt Range.

A large area of Lower Triassic sediments is exhibited in the Ceratite beds of the Salt Range. Here, as in the Himālayas, the most

interesting problems in correlation were those concerning the termination of the Permian system. In both areas, however, the sedimentation introducing the Triassic system was strikingly different. In the Central Himálayas arenaceous deposits are entirely wanting, and the Lower Trias is made up of limestones and shales. In the Salt Range arenaceous limestones, calcareous sandstones and marls play a very important part. Those rocks contain rich fossil faunæ, and their classification by Wynne, Waagen and Noetling constitutes one of the most interesting chapters in Indian Geology.

This difference in the development of the Lower Triassic deposits in the Himálayas and in the Salt Range renders an attempt at correlation difficult, notwithstanding the considerable number of species common to both regions. A discussion on this subject between A. v. Krafft, Noetling and Diener indicates considerable confusion, and the inference to be drawn from a study of its results is that the palæontological evidence available is not sufficient for a correlation of the strata down to the smaller divisions of the scale. A detailed account of this discussion has been given by Diener in Vol. VI, No. 1, of the "Himálayan Fossils."

The youngest Himálayan fauna from the top of the chocolate limestone of Jolinka (Byans) has been correlated with that of the upper Ceratite limestone by A. v. Krafft. This homotaxis has been accepted unanimously by all authors dealing with this subject. There is, indeed, a close agreement in the character of the two faunæ, that of Jolinka consisting exclusively of species of the genus *Sibirites*, one of them very closely allied to *Sibirites* (*Ceratites* *antea*) *inflatus* Waag.

The Hedenstrœmia beds are in a general way equivalent to the upper division of the Ceratite marls (in Noetling's interpretation) or to the zone of *Konnickites volutus* Noetl. and to the Ceratite sandstone (*Flemingites Flemingianus* beds).

The Meekoceras beds probably correspond to the lower division of the Ceratite marls (zone of *Prionolobus rotundatus* Noetl.) and to the lower Ceratite limestone.

The most obscure point in the controversy is the problem of the correlation of the Otoceras beds, owing to the different lithological development in the two regions and to the absence of the most characteristic elements of the Otoceras fauna from the Salt Range. Diener looks for

equivalents of the *Otoceras* beds in the unfossiliferous shales and sandstones, which in the sections of Chideru and Virgal separate the Chideru group of the Upper Productus Limestone from the Ceratite formation. Noetling correlates them with his zone of *Euphemus indicus* of the Upper Productus Limestone, but this correlation is not based on palæontological evidence, not one single identical species having been found in the two horizons.

The special development, which the Lower Triassic faunæ have taken in those two regions, renders it evident that a correlation of the minor subdivisions cannot be made except in a most general way, and always with the mental reservation that their lower and upper boundaries do not strictly coincide.

When the examination of the fossils collected in the Ceratite beds by Noetling and Koken is finished, it may be possible to form a better scheme of classification, in which the relative positions of the Lower Triassic strata in the two regions may be determined more exactly. For the present the following tabular statement will show the conclusions reached, as indicated above, by those best qualified to determine the relations of the lower Himálayan Trias with the Ceratite formation of the Salt Range :—

Himálayas	Salt Range	
	Noetling, 1905.	Diener, 1908.
Zone of <i>Sibirites spiniger</i> (Byans).	Upper Ceratite limestone.	Upper Ceratite limestone.
Hedenstroemia beds (zone of <i>Flemingites Rohilla</i>).	Ceratite sandstones.	Ceratite sandstones.
	Ceratite marl.	Ceratite marl.
Meekoceras beds (zone of <i>Meekoceras Markhami</i>).	Lower Ceratite limestone.	Lower Ceratite limestone.
Otoceras beds (zone of <i>Otoceras Woodwardi</i>).	Zone of <i>Euphemus indicus</i> (Upper Productus limestone).	Unfossiliferous clay and shales.
Kuling (Productus) shales.		Upper Productus Limestone.

h. Correlation with the lower Trias of Europe, North America and Siberia.

Until the examination of Hayden's and A. v. Krafft's fossil materials from Spiti the evidence for the Lower Triassic age of the Hedenstroemia beds was merely circumstantial. Until then no affinities were known between their fauna and that of the Campil or upper Werfen beds of the Mediterranean region.

Noetling¹ in his discussion of the age of the Otoceras beds thinks that the fauna of the Hedenstroemia beds might be attributed to the lower Muschelkalk or to the Lower Trias with equal reason, and in the introduction to his synopsis of the Himálayan Trias² he even emphasizes the assertion that the presence of Lower Trias in the Himálayas merely rests on palæontological subtilties, without any decisive proof.

Similar opinions have been expressed more or less definitely by other writers.

Three faunistic elements connecting the Alpine Campil beds and the Hedenstroemia beds, which have been discovered among the *Cephalopoda* from the latter group, are sufficient to show that those two stages may be placed in general parallelism. These three species of *Cephalopoda* are:—

Tirolites injucundus Krafft.

Xenodiscus asiaticus Krafft.

Meekoceras pseudoplanulatum Krafft.

Tirolites injucundus is an ammonite of the group of *Tirolites spinosi*, and its discovery in the Himálayas has been so much the more astonishing, because the absence of *Tirolitinae* was considered by E. v. Mojsisovics as one of the most remarkable faunistic characters of the Indian zoo-geographical region.

Xenodiscus asiaticus is distinguished from *Paraceratites prior* Kittl. from the Campil beds of Muc by some very subordinate details only. A near affinity of *Meekoceras pseudoplanulatum* to *Meekoceras caprilense* Mojs. from the Campil beds of the south-eastern Tyrol is also extremely probable.

¹ *Neues Jahrb. f. Miner., Beil. Bd., XVIII, p. 551.*

² *Asiatische Trias, Lethæa mesozoica, l. c., p. 125.*

Thus a solid base for a direct correlation between the Hedenstrœmia beds of the Himálayas and the Alpine Campil beds has been established by A. v. Krafft's and Hayden's discoveries. Nevertheless the affinities of the two faunæ are rather distant, all the nearly allied species being of extremely rare occurrence, either in one of the two regions or in both of them.

But the gap, by which the two faunæ had hitherto been separated, has been bridged over —partly at least—by the interesting discovery of Campil beds in North Albania in a development of red limestones (Hallstatt facies). This is a cephalopod facies of the Campil or upper Werfen beds formerly unknown in Europe, which has yielded a considerable number of fossils near the village of Keira, about 25 km. to the east of Skutari. The fossils, which were collected by F. v. Nopcsa in 1906 and 1907, have been described by G. v. Arthaber,¹ who correctly refers to the astonishing association of Mediterranean, Indian and Pacific types. The Indian types even predominate in number. Among them the following may be mentioned :—

Pseudosagoceras multilobatum Noetl.

Xenaspis mediterranea Arth.

Nannites Herberti Dien.

Monophyllites Hara Dien.

Meekoceras marginale Arth.

Hedenstrœmia sp. ind.

This fauna, which contains several types, chiefly Mediterranean (*Tirolites seminudus* Mojs., *Celtites keirensis* Arth.) but also some Californian (*Columbites*), connects the Lower Triassic faunæ of India and Europe much more closely than had been hitherto anticipated. In contradiction to Noetling's views there can be no further doubt that during the Lower Trias the great central sea of the Tethys extended from the Mediterranean to the Indian basin in the shape of an open canal across the present mountain ranges of Afghanistan and Northern Persia, by which an intercommunication of the faunæ of both regions became possible within certain limits.²

¹ G. v. Arthaber : Ueber die Entwicklung der Untertrias in Albanien und ihre faunistische Bewertung. *Mitteil. Geol. Ges. Wien*, I, 1908, pp. 245-289.

² New researches in 1908 by F. v. Nopcsa have added considerably to our knowledge of the Lower Triassic faunæ of Albania. The rich collections of fossils which were made in some favourable places, enable us now to appreciate the

It has been demonstrated by J. P. Smith, that the Tethys of the Lower Trias extended from India to the Western States of North America across the entire Pacific Ocean. There are some strong affinities between the Lower Triassic faunæ of the Himálayas and Eastern Siberia on one side and of California and Idaho on the other, but an attempt to correlate the stratigraphical subdivisions on either side of the Pacific Ocean meets with considerable obstacles, owing to the differences in the geological history of the two regions.

In America the oldest fauna of Lower Triassic age is concentrated in the Meekoceras beds of California and Idaho. According to J. P. Smith¹ this fauna shows an intimate relationship to that of India and Eastern Siberia (Ussuri district) and none to the fauna of the Mediterranean region. After the deposition of the Meekoceras beds an invasion of Mediterranean forms took place. The fauna of the Tirolites beds, which is characterised by this incursion of Mediterranean types—three European species of *Tirolites*, one of *Dalmatites* and one of *Dinarites*—is decidedly the same as that of the upper Werfen or Campil beds in the Alps. But this incursion was only sporadic, for in the overlying Columbites beds there is an assemblage of Mediterranean, Asiatic and autochthonous forms.

All those three horizons of the Lower Trias are exposed in Idaho in a continuous section in Paris canyon, the Columbites beds occurring 15 metres above the Tirolites horizon and 90 metres above the main layer of the Meekoceras beds.

importance of the association of Mediterranean, Pacific and Indian elements in this fauna.

The results of G. v. Arthaber's examination of these new materials have not yet been published, but I owe to Prof. v. Arthaber the valuable and interesting communication, that both the Indian and Pacific elements far exceed the Mediterranean ones. *Columbites* and *Pseudosageceras* are represented in large numbers in the new collections. The local peculiarities are rather remarkable. A striking character is the presence of a primitive stock of generalized forms, which might be considered as radicles of different types of *Ceratitidae* and of *Monophyllites*. A primitive ancestor of the genus *Tropites* deserves special mention. The presence of the genus *Japonites*, which hitherto has not been found in beds older than Muschelkalk, forms a sharp contrast with those generalized forms which give a rather old aspect to the Lower Triassic fauna of Albania.

¹ A. Hyatt and J. P. Smith: Triassic cephalopod genera of North America, *U. S. Geol. Survey, Profess. Pap.* No. 40, Washington, 1905—J. P. Smith: The stratigraphy of the Western American Trias. *Sonderabdr. aus Koenen Festschrift*, 1907, pp. 377-394.

Now the most important moment in the geological history of Idaho during the Lower Triassic epoch, the opening of a new connection between the American and Mediterranean regions at the beginning of the Tirolites stage, has left only faint traces in the deposits of the Himálayan Lower Trias. That this invasion of Mediterranean types did not take place through India, is evident from the fact that the admixture of such types in the Hedenstrœmia beds is extremely scanty, and that no fauna comparable with that of the Tirolites beds of Idaho has ever been met with either in the Salt Range or in the Himálayas.

The difficulty of correlating the subdivisions of the American and Indian Lower Trias is chiefly due to the fact that the faunistic influence of India on the American region was never counterbalanced by an incursion of American forms into the Indian province. The American Meekoceras-fauna is probably—and in this opinion I agree entirely with J. P. Smith—of Asiatic origin, for there is nothing known in the American Permian that could have given rise to the forms of the Meekoceras zone. In India, however, no autochthonous types of the American Lower Trias are known, which, like *Columbites*, have reached the Mediterranean region as sporadic immigrants, but not the Indian Triassic province.

Near affinities are therefore restricted to the fauna of the American Meekoceras beds, but this fauna shows, indeed, a strong kinship both with the fauna of the lower and upper divisions of the Himálayan Lower Trias. Not less than twelve genera are common to both regions, namely, *Meekoceras*, *Aspidites*, *Koninckites*, *Flemingites*, *Xenodiscus*, *Ophiceras*, *Pseudosageceras*, *Hedenstrœmia*, *Sibirites*, *Proptychites*, *Nannites*, *Tirolites*.

There are equally close relationships with the fauna of the Meekoceras beds of the Himálayas and of the Hedenstrœmia beds. There is a small number of very characteristic species, which point to a direct correlation with the Hedenstrœmia beds. *Hedenstrœmia Mojsisovicsi* is represented in America by *H. Kossmati*, *Pseudosageceras multilobatum* by *Ps. intermontanum*, *Flemingites Salys* by *Fl. cirrus*. Among three species of *Sibirites* two are closely allied with forms from the Upper Ceratite limestone of the Salt Range. On the other hand the affinities with the Himálayan Meekoceras beds are at least equally close, and even with the fauna of the Ophiceras bed of the Otoceras zone in Spiti.

Four species of *Ophiceras*, among them *O. cf. Sakuntala* Dien. and *O. cf. gibbosum* Griesb., together with *Meekoceras cf. Hodgsoni* Dien., have been quoted from the Meekoceras beds of south-eastern Idaho by J. P. Smith.

This learned author correlates the Meekoceras beds of America with the Hedenstrœmia beds, which, according to his view have been placed too high in the column by Diener. But the Hedenstrœmia beds cannot be regarded as equivalents of the Alpine Seis beds, since their fauna is undoubtedly homotaxial with the fauna of the Campil beds, as is evident from its affinity to the fauna of Kcira in Albania. The presence of a species of *Tirolites* in the Hedenstrœmia beds and the persistence of a small number of Indian types in the Columbites beds of Idaho are rather in favour of a correlation of the Hedenstrœmia stage with the higher subdivisions of the American Lower Trias.

Although there is a great probability of a homotaxis of the Hedenstrœmia beds with the whole of the upper divisions of the Lower Trias of Idaho, we should not forget that the fauna of the American Meekoceras zone contains elements of the Hedenstrœmia beds, Meekoceras beds and even Otoceras beds. This is one of the instances demonstrating the difficulty of correlating terranes in widely separated areas, although this correlation has been attempted on the basis of a large number of fossils either generically or specifically identical. But the natural divisions are not the same in India and Idaho and therefore they cannot be correlated except in the most general way.

The development of Lower Triassic rocks near Vladivostok in the southern Ussuri district of the coast province of Eastern Siberia¹ is another illustration of the uniformity of the fauna around the Pacific Ocean during the Lower Triassic age. The association of genera is the same as exhibited in the Meekoceras beds of California and Idaho. The ammonites have their nearest representatives in the Meekoceras zone of the Himalayas—both *Meekoceras Varaha* and *M. boreale* have been found in the Proptychites beds of Vladivostok—but the presence of a species referable to *Ophiceras Sakuntala* Dien. indicates, perhaps, also a correspondence with the Ophiceras bed of the Otoceras stage.

¹ C. Diener: Triadische Cephalopodenfaunen der ostsibirischen Kuestenprovinz. *Mém. Com. Géol. St. Pétersbourg*, 1895, Vol. XIV, No. 3.

The evidence furnished by a comparison of the lamellibranchs must be considered as very important, justifying a direct correlation with the Alpine Seis beds, with which the fauna of Vladivostok has not less than twelve species in common.¹

Ammonites of Lower Triassic age, which can, however, not be assigned to a definite stratigraphical horizon, have been quoted from Yunnan by Douvillé, and from the Semenow Range (N. E. Tibet) by Schellwien.

Less close than the relations of the Indian Meekoceras beds with the fauna of Vladivostok are those of the Hedenstroemia stage with the Olenek beds of Northern Siberia. The richest Triassic fauna from Siberia hitherto known has been collected from a concretionary limestone imbedded in dark shales, at the mouth of the Olenek river. Not less than forty species of Cephalopoda have been described by E. v. Mojsisovics.² Nevertheless the age of the fauna has been a subject of controversy.

E. v. Mojsisovics considered the Olenek beds as the homotaxial equivalent of the Campil beds, although no identical or even nearly allied species were known to him from both regions and this correlation was only based on the general zoological character of the Olenek fauna. A considerably younger age was assigned to the latter by Noetling.³ His opinion is supported by the three following arguments:— (1) *Ceratites* (*Keyserlingites*) *subrobustus* Mojs. has its habitat in the zone of *Spiriferina Stracheyi* of the Himálayan Muschelkalk; (2) in India the genus *Ceratites*, which in the Olenek fauna is represented by several groups, does not make its appearance before the commencement of the Muschelkalk; (3) the differences between the faunæ of the Indian Lower Trias and of the Olenek beds are sufficiently remarkable to exclude their homotaxis.

¹ A. Bittner: Versteinerungen aus den Triasablagerungen des Sued-Ussuri-gebietes, etc., *ibidem*, Vol. VII, No. 4, 1899. P. v. Wittenburg: Neue Beiträge zur Geol. und Paläont. d. Werfener Schichten Suedtirols mit Beruecksichtigung der Schichten von Wladiwostok. *Centralbl. f. Min.*, 1908, p. 67. Notiz ueber Trias und Jura bei Wladiwostok. *Neues. Jahrb. f. Min.*, 1909, Bd. I, p. 1.

² E. v. Mojsisovics: Arktische Triasfaunen, *Mém. Acad. impér. des sciences, St. Pétersbourg*, 1886, VII. Sér., Vol. XXXIII. Ueber einige arktische Triasammoniten des noerdl. Sibirien. *ibidem*, 1888, Vol. XXXVI, No. 5.

³ F. Noetling: Asiatische Trias, *Lethæa mesozoica*, I, p. 200.

In a special paper treating with the problem of the age of the Olenek beds¹ I have tried to refute Noetling's arguments. The Indian and Siberian species of *Keyserlingites* (*Ceratites subrobusti*) are not identical and do not even belong to the same group of forms. In the Himálayas the genus *Ceratites* is not restricted to the Muschelkalk, but is represented in the Hedenstræmia beds by typical species of the group of *circumPLICATI* (*Hollandites*). There are some affinities between the Olenek fauna and the Hedenstræmia stage, but none at all with the Himálayan Muschelkalk. *Hedenstræmia Mojsisovici* Dien. is either identical or very closely allied to the Siberian species, which has been described as *Meekoceras* *sp. ind. aff. Hedenstræmia* by E. v. Mojsisovics. There are also strong affinities between some Indian and Siberian representatives of the genera *Meekoceras* and *Xenodiscus*, as has been suggested by Frech, especially between *Xenodiscus rotula* Waag. and *X. hyperboreus* Mojs. But the most important argument in favour of a correlation with the Hedenstræmia beds is the occurrence of *Xenodiscus*, *Meekoceras*, *Aspidites*, *Hedenstræmia* and *Prosphinnigites* in the Olenek fauna, all genera, which in the Himálayas are restricted to the Lower Trias and do not range into the Muschelkalk.

The faunistic affinities of the Olenek beds with the Columbites beds of North America, as advocated by J. P. Smith, is in accordance with this correlation.

On the other hand Noetling is certainly right in assuming that the connection of the Indo-Chinese and Northern Siberian provinces has not been a very close one. The peculiar character of the Olenek fauna, especially the enormous preponderance of *Dinarites spiniplicati* (*Olenekites* Hyatt), is indicative of a comparative isolation of this basin of the Triassic Arctic sea.

i. The Permo-Triassic boundary.

The determination of the upper limit of the Permian rocks in the marine series of India did not trouble the students of the geological formations in the Himálayas until it had been suggested by Noetling's studies in the Salt Range.

¹ C. Diener: Das Alter der Olenekschichten Sibiriens. *Centralblatt. f. Min., etc.*, 1908, p. 233.

By C. L. Griesbach the base of the Himálayan Trias had been assumed to lie at the top of the Permian Productus, or Kuling, shales, which in all normal sections of Spiti and Painkhanda are overlain conformably by a series of dark thin-bedded shales and limestones, which have yielded the fauna of the *Otoceras* beds.

Griesbach himself determined the *Otoceras* beds as Triassic at the time of their discovery (1879). In his memoir on the geology of the Central Himálayas (1891, p. 71) he looked upon them as a true passage bed between the Permian and Triassic systems, "as a horizon still lower than the Werfen beds of the Alps, and considerably lower than what is understood now as Bunter," but nevertheless decided to include them with the Lower Trias (l. c., pp. 121, 146, 174, 175, 177, 219).

Waagen¹ correlated the Himálayan *Otoceras* stage with the *Otoceras* beds of Julfa in Armenia and consequently included it in the Upper Permian, although he considered it to be younger than the Jabi or Cephalopod beds of the Upper Productus Limestone, "because the mesozoic types seemed to predominate over the palæozoic ones" (l. c., p. 232).

The correlation with the Permian *Otoceras* beds of Julfa was refuted by E. v. Mojsisovics,² because the species of *Otoceras* in the last mentioned deposits occupy a remarkably lower stage of development than the Indian ones. The *Otoceras* stage of the Himálayas was therefore regarded as the oldest cephalopod-bearing horizon of the Lower Trias in India. In a subsequent paper Waagen³ acknowledged the Triassic character of the *Otoceras* fauna and defined the age of the beds including it as Lower Triassic.

In 1897 C. Diener,⁴ after his examination of the fossil materials collected by Griesbach and by the expedition of 1892, supported the view given by E. v. Mojsisovics, by new evidence, enumerating the remarkable differences between the *Otoceras* faunæ of Julfa and of the

¹ W. Waagen : Salt Range Fossils, *Palæont. Ind.*, ser. XIII, Vol. IV, Geological Results, p. 225.

² E. v. Mojsisovics : Vorläufige Bemerkungen ueber die Cephalopodenfaunen der Himálaya-Trias. *Sitzgsber. kais. Akad. d. Wissen sch. Wien*, 1892, CI, pp. 372-378.

³ E. v. Mojsisovics, W. Waagen, C. Diener : Entwurf einer Gliederung der pelagischen Sedimente des Triassystems, *ibidem*, CIV, 1895, p. 1286.

⁴ C. Diener : Himálayan Fossils, *Palæont. Ind.*, ser. XV, Vol. II, Pt. 1.

Shalshal cliff, and emphasizing the decidedly Triassic aspect of the latter. In his summary (p. 172) he considers the Indian *Otoceras* beds as forming the base of the Buntsandstein, that is the lowest Triassic beds following immediately above the upper boundary of the Permian deposits, without any distinct demarcation. "The fauna of *Otoceras Woodwardi* is the oldest fauna of Triassic age containing cephalopoda, which has as yet been discovered. It is somewhat younger than the *Otoceras* beds of Julfa, but older than the cephalopod horizon of the Alpine Werfen beds.¹ In the Alps no cephalopod-bearing strata correspond to this Himálayan horizon, but only the bivalve fauna of the lower division of the Werfen beds (Seiser Schichten of F. v. Richthofen)."

This correlation of the *Otoceras* stage with the Seis beds has been fully corroborated by A. Bittner² who on the strength of his examination of the *Lamellibranchiata* collected by Griesbach and Diener, compared them with species from the lower division of the Werfen beds (horizon of Seis) and decided that they were also of Triassic, not of Permian, age.

A different interpretation of the age of the *Otoceras* fauna was attempted in 1900 by F. Noetling after a tour among the Ceratite beds of the Salt Range.

In his "Geological Results" W. Waagen had come to the conclusion that a stratigraphical gap existed in the sequence of the Salt Range between the Permian *Productus* limestone and the Ceratite beds. Noetling, who was deputed to the Salt Range, found Waagen's statement contradicted by actual facts. He held the view that the entire Ceratite formation must be included with the Permian system, the gradual passage from the *Productus* limestone to the Ceratite beds making a stratigraphical subdivision into two great periods an impossibility. He also reported that he had discovered *Otoceras* in the Ceratite marls, which must consequently be correlated with the Himálayan *Otoceras* beds.³

¹=Campil beds (F. v. Richthofen).

² A. Bittner: Himálayan Fossils, *Palæont. Ind.*, ser. XV., Vol. III, Pt. 2, pp. 74, 76.

³ F. Noetling: *General Report, Geol. Surv. of India*, 1899-1900, p. 42.—Ueber die Auffindung von *Otoceras* sp. in der Salt Range, *Neues Jahrb. f. Min.*, 1900, p. 130.

This report soon turned out to be incorrect, and the correlation of the Himálayan *Otoceras* beds with the *Ceratite* marls consequently fell to the ground. But the discussion of the true limit between the Permian and Triassic systems in the Indian zoo-geographical region was nevertheless continued by C. Diener, A. v. Krafft and F. Noetling.

Noetling's view set forth in his paper in the *Neues Jahrbuch* was answered by Diener,¹ who maintained the Triassic age of the *Otoceras* beds and of the corresponding beds in the Salt Range. He claimed that no proof had been given of their homotaxis with any extra-Indian strata of recognised Permian age, but that their bivalve fauna was decidedly in favour of a parallism with the Seis (lower Werfen) beds.

Noetling's next paper² is controversial and adds little to the settlement of the problem. But in 1901 the question of the true stratigraphical position of the Himálayan *Otoceras* beds was taken up by A. v. Krafft. During the summer of 1899 this author had worked out the sequence of Permian and Triassic strata in Spiti, together with H. Hayden, but the incorrect report of the discovery of *Otoceras* in the Salt Range led him to the conclusion that the *Otoceras* beds were equivalent to the *Ceratite* marls and to the lower *Ceratite* limestone of the Salt Range.³ In the next season, however, he took an entirely different view of the subject. He divided the series between the Kuling shales and the *Hedenstrœmia* beds into three palæontological zones, the *Otoceras* bed *s. s.*, the *Ophiceras* bed and the *Meekoceras* bed. The *Meekoceras* bed is referred to the Lower Trias, the age of the *Ophiceras* bed is left doubtful, there being no decisive proof of its fauna being either Permian or Triassic, but the *Otoceras* bed *s. s.*, is correlated with the Chideru group or Upper *Productus* Limestone, on the strength of an identification of *Medlicottia* (*Episageceras*) *Dalailamæ* Dien. with *Medlicottia Wynnei* Waag. from the zone of *Euphemus indicus* in the Salt Range.⁴

¹ C. Diener: Ueber die Grenze des Perm-und Triassystems im ostindischen Faunengebiet, *Centralbl. f. Miner., etc.*, 1900, p. 1.

² F. Noetling: Die *Otoceras* beds in Indien, *Centralblatt. f. Miner., etc.*, 1900, p. 216.

³ A. v. Krafft: Stratigraphical notes on the mesozoic rocks of Spiti, *Gen. Report, Geol. Sur. of India*, 1899-1900, p. 203.

⁴ A. v. Krafft: Ueber das permische Alter der *Otoceras*-Stufe des Himalaya, *Centralbl. f. Miner., etc.*, 1901, p. 275.

This paper was again answered by Diener, who refused to admit the identity of the two species of *Medlicottia* (*Episagceras*).¹

In the meantime an extensive memoir on the Permian and Triassic rocks of the Salt Range was published by Noetling.² Revising his former views on the Permian age of the Ceratite formation, he now admits their correlation with the Triassic system and draws the boundary between the two zones of *Euphemus indicus* below, and *Celtites* *sp.* of the lower Ceratite limestone above. The Otoceras beds of the Himálayas are no longer considered as equivalent to the Ceratite marls. as in 1900, but to the Upper Productus limestone. Noetling places the Otoceras bed *s. s.* even lower in the series than A. v. Krafft. correlating it with the Permian zone of *Bellerophon impressus* and the overlying Ophiceras bed with the zone of *Euphemus indicus* of the Chideru group.

These views have been set forth more fully in a chapter of the *Lethæa Palæozoica*, dealing with the Permian rocks of the Himálayas,³ and support has been given to them by F. Frech,⁴ who correlated the Indian Otoceras beds with the Permian Bellerophon limestone of the Eastern Alps.

Both papers were answered in a short note by Diener, who commented on the remarkable change in Noetling's system of correlation.⁵

The attitudes of the two disputants are brought out clearly by their principal reports on the problem of the Permo-Triassic boundary in the Himálayas, which appeared in 1905. An exhaustive study of the stratigraphy and age of the Otoceras beds was published by Noetling who divided the uninterrupted complex of dark limestone and shaly clay with its uniform fauna into three palæontological

¹ C. Diener: Ueber das Alter der Otoceras beds des Himalaya. *ibidem*, p. 513.

² F. Noetling: Beiträge zur Geologie der Salt Range, insbesondere der permischen und triadischen Ablagerungen. *Neues Jahrb. f. Min., etc.*, Beilagebd. XIV, p. 467.

³ F. Noetling: Die Dyas des Himalaya, *Lethæa palæozoica*, II, p. 653.

⁴ F. Frech: *ibidem*, p. 577.

⁵ C. Diener: Zur Frage des Alters der Otoceras beds in Himalaya, *Centralbl. f. Min.*, 1901, p. 655.

zones and draws the boundary between the Permian and Triassic systems below the Meekoceras beds.¹

This study, which was based on a personal examination of the Shalshal cliff in 1900, was answered by Diener, who declared that neither lithological nor palæontological nor historical reasons were valid for a decision in favour of Noetling's opinion.² In a subsequent paper on the genus *Episageceras*³ Noetling himself admitted the incorrectness of A. v. Krafft's identification of *Episageceras Dalailamæ* Dien. with *E. Wynnei* Waag., thus acknowledging his mistake in having accepted this identification as a proven fact.⁴

The conclusions reached in those papers by Noetling have been maintained in his synopsis of the stratigraphy of the Trias in Asia.⁵

The only result which this history of correlation emphasizes, is the fact that all attempts to assign the Otoceras stage definitely to one system or the other, have hitherto failed. The present state of the discussion may be summed up as follows:—

From a palæontological point of view the classification of the beds included between the Kuling, or Productus, shales, of undoubtedly Permian age, and the Hedenstrœmia stage, as proposed by Noetling, is too minute, and a combination of the three zones distinguished by him within the Otoceras beds will better express our present knowledge regarding their true faunistic relations. The Meekoceras beds have been referred unanimously to the Trias. There is indeed no doubt about their parallelism with the Seis or lower Werfen beds, since the homotaxis of the overlying Hedenstrœmia stage with the Campil beds of the Eastern Alps has been proved by the recent discovery of the fauna of Kcira in Albania. The Otoceras beds have been included with the Permian system by Noetling,

¹ F. Noetling: Ueber das Alter der Otoceras Schichten von Rimkin Paiar (Painkhanda) im Himalaya. *Neues Jahrb. f. Mineral, etc.*, Beilagebd., XVIII, p. 518.

² C. Diener: Ueber die stratigraphische Stellung der Otoceras beds im Himalaya, *Centralbl. f. Miner., etc.*, 1905, pp. 1-50, 36-45.

³ F. Noetling: Ueber *Medlicottia* und *Episageceras* aus den permischen und triadischen Schichten Indiens. *Neues Jahrb. f. Mineral, etc.*, Beilagebd., XIX, p. 369.

⁴ *Lethæa palæozoica*, II, p. 656.

⁵ Asiatische Trias. *Lethæa mesozoica*, Bd. I, Trias, 2 Lieferg., 1905, p. 127.

with the Trias by Diener, but those two authors are entirely in accord in acknowledging the fact that there is a gradual transition of the deposits from the Kuling shales to the Hedenstroemia beds, without any break or unconformity.

Since the discussion of the Permo-Triassic problem in the Himálayas had come to a preliminary close in 1905, much new evidence has been gathered from an examination of the Triassic fossils from Spiti and Painkhanda by A. v. Krafft and C. Diener, from the study of the Meekoceras fauna in California and Idaho by J. P. Smith, and from the discovery of a rich Permian fauna in the Bellerophon limestone of Carniola by Kossmat and Schellwien. A sufficient number of facts, I believe, has been accumulated now to enable us to delimit the Permian and Triassic systems on the same basis in the Eastern Alps and in the Himálayas.

Noetling has laid special stress on the absence of any defined break in the series between the Hedenstroemia beds and the Productus shales. Nevertheless he draws his boundary *below* the Meekoceras beds, not above them, where the lithological change is certainly marked more sharply. But I shall not insist on this objection to his division of the two systems, because in my opinion lithological affinities can never give a clue to the true position of horizons in the standard stratigraphical scale. The object of correlation is and has been to bring newly discovered horizons into their proper places in systematic classifications already established. Such correlations, however, can be made with any precision on *palæontological* evidence only, the apparent lithological affinity of two strata never being a safe means for their association in one stratigraphical subdivision.

A remarkable instance may be quoted here regarding the question of the Permo-Triassic boundary in the Eastern Alps, which in many respects is similar to the same problem in India.

There is no unconformity between the Permian Bellerophonkalk and the shales of the lower Werfen (Seis) beds, but the lithological contrast between the two groups is rather sharply marked, considerably more so, as a rule, than between the Productus shales and the Otoceras stage. Nevertheless sections have been found, where the Bellerophon limestone passes gradually into the overlying shales. Now in the vicinity of Sarajevo a very interesting section has been described by E. Kittl (*Geologie der Umgebung von Sarajevo. Jahrb. K. K. Geol. Reichsanst.*, 1904,

LIII. p. 17), where a bed of limestone containing fossils of the Bellerophonkalk is intercalated in shales lithologically identical with those of the Werfen beds. It is evident that in this section the highest beds of Permian age are developed in the facies of the Triassic Werfen shales and that the lithological boundary does not coincide with the true limit of the two systems. A development of Triassic limestones within the shales at the base of the Seis beds has been described recently by F. v. Kerner (Die Trias am Suedrande der Svilaja Planina, *Verhandl. K. K. Geol. Reichsanst.*, 1908, p. 263).

The Permian age of the *Otoceras* beds was defended on this lithological basis for a number of years against the counter-evidence of fossils. Noetling had indeed no palæontological evidence in favour of the supposed homotaxis of the Himálayan *Otoceras* beds with the Chideru stage of the Salt Range. His only reasons for assigning a Permian age to the *Otoceras* stage, as deduced from a study of its fossils, are the following :—

- (1) the genus *Otoceras* is only known from Permian rocks ;
- (2) *Episageceras Dalailamæ* is a Permian species, so far as we can judge from the character of its suture-line.

The fallacy in those two assumptions is so evident that it should not have deceived able geologists like Kayser (*Lehrbuch der Geologie*, II, Formationskunde, 3. Aufl. 1908, p. 301) or Steinmann (*Einfuehrung in die Palæontologie*, 2. Aufl. 1907, p. 326).

It is true that the genus *Otoceras* is known outside the Himálayas from Permian rocks only, a small number of species, represented by a few fragmentary examples, having been collected from a single locality (Julfa on the frontier of Persia and Russian Armenia). But there is not a single case of specific identity with Himálayan forms. The Armenian species of *Otoceras* are associated with a rich fauna of distinctly Palæozoic aspect. The numerous types of *Productidæ*, *Orthidæ*, *Spiriferidæ*, *Gastrioceras*, differ so widely from anything that is seen in the fauna of the Indian *Otoceras* beds, that the presence of the genus *Otoceras* at Julfa does not justify the assumption of its being restricted to the Permian. *Hungarites*, the nearest ally of *Otoceras*, is certainly a Triassic genus, although it makes its first appearance in the *Otoceras* beds of Julfa. *Xenodiscus* also ranges from the true Permian into the upper division of the Lower Trias. The species of *Otoceras*, which have

been described from the fauna of Julfa, are leading fossils of the Upper Permian, but the *genus Otoceras* is not.

A similar remark applies to *Episageceras Dalailamæ*. The genus *Episageceras* in Noetling's interpretation is represented by three species only. *Episageceras Wynnei* Waag., from the Upper Productus limestone of the Salt Range, *E. Dalailamæ* Dien., from the *Otoceras* beds of the Himálayas. *E. latidorsatum* Noetling from the zone of *Prionolobus rotundatus* (lowest Ceratite marls) of the Salt Range. In its sutures *E. Dalailamæ* agrees more nearly with the Permian *E. Wynnei* than with the Triassic *E. latidorsatum*. This affinity is considered sufficient for claiming a Permian age for *E. Dalailamæ*. But this conclusion far exceeds the limit of the true relations of the elements of organic form to geological age, and the specific discrepancy between *E. Dalailamæ* and *E. Wynnei* cannot be corrected by interpreting *E. Dalailamæ* as a representative of a Permian group of forms in the face of the absence of all faunal guides pointing to a Permian age of the *Otoceras* beds.

By this method of correlation the Permo-Triassic problem in the Himálayas has not been solved but simply reserved.

Noetling looks upon the genus *Otoceras* and the group of *Episageceras Dalailamæ* as leading fossils of the Permian system and infers from their presence in the Indian *Otoceras* beds a Permian age for that stage. But in reality it is this character of the two ammonites quoted above as leading fossils of the Permian system, which ought to be proved first and this can only be done with reliable evidence of the Permian age of the *Otoceras* beds. Provided the *Otoceras* beds of India be really Permian, then, but only then, *Otoceras* is indeed a Permian genus. Otherwise it would be common to the Permian and the Trias, as are *Xenodiscus* and *Hungarites*. No diagnosis of the age of the formation can be based on the presence of *Otoceras*, but the stratigraphical value of the genus depends on the way in which the problem of the *Otoceras* beds is solved.

All mistakes in the correlation of the Indian *Otoceras* beds were an outcome of the faultiness of this method. It has therefore been necessary to go into full details, since a general reliance among European geologists upon Noetling's authority still stands in the way of the acceptance of the truth.

Positive palæontological evidence is decidedly contradictory to the assumption of a Permian age for the Indian *Otoceras* beds. The general

character of the cephalopod fauna is what we should expect to find in a Mesozoic horizon, the overwhelming majority of the ammonites being provided with ceratitic sutures. This character is not exhibited in any Permian cephalopod fauna hitherto known.

Among the genera of ammonites *Meekoceras*¹ and *Ophiceras* are in common with the fauna of the Triassic Meekoceras beds. *Proptychites* and *Prosphingites* are Triassic genera. In the Meekoceras beds of Idaho species of the *Ophiceras* bed in Spiti are associated with an undoubtedly Triassic fauna. Among those species which have been quoted by J. P. Smith² three are probably identical with Himálayan forms, namely :—

Ophiceras cf. Sakuntala Dien.

„ *cf. gibbosum* Griesb.

Meekoceras cf. Hodgsoni Dien.

Two other species of *Ophiceras* are very nearly allied to Indian ones, namely, *Ophiceras Spencei* Hyatt et Smith to *O. ptychodes* Dien., and *O. Dieneri* Hyatt et Smith to *O. demissum* Opp.³

All the numerous types of Palæozoic brachiopods, which are the predominating and most characteristic element both in the Productus Limestone of the Salt Range and in the Kuling shales of the Himálayas, are completely absent from the Otoceras beds. There is no stratigraphical break in the uninterrupted sequence of beds, which in the Himálayas connects the Permian and Triassic systems, but there is a distinct palæontological break or hiatus at the base of the Otoceras beds. In the Himálayan region there is certainly no gradual shading-off from a Palæozoic to a Mesozoic marine fauna through an intermediate group, but a sharply defined limit, which none of the characteristic species of Permian brachiopods transgresses. This absolute distinction between the brachiopods of the Kuling shales and of the Otoceras beds is so sharp that *the limit between the two faunæ offers itself as the most natural boundary of the two systems.*

I must object strongly to Noetling's criticism upon the importance of the absence of the Palæozoic brachiopod fauna from the Otoceras

¹ Noetling's report of the absence of the genus *Meekoceras* from the Otoceras stage has turned out to be incorrect.

² J. P. Smith : The stratigraphy of the Western American Trias, l. c., p. 394.

³ A. Hyatt and J. P. Smith : Triassic cephalopod genera of America, l. c., pp. 118, 119.

stage. Being obliged to acknowledge the fact, he attempts to lessen its stratigraphical value by a hypothesis, which is, perhaps, the best argument that could be produced against an adoption of his views.

As an explanation of the sudden extinction of Palæozoic brachiopods in the Salt Range he suggests an increase of the temperature of the sea, which he believes to have advanced from north to south. Thus the Palæozoic brachiopods still persisted in the Salt Range after they had already been extinguished in the Himálayas. The biological change was not synchronous in the two regions and the line of demarcation, which in the Salt Range separates the two systems, does not separate them in the Himálayas.

When we examine this argument critically, we find that the theory to account for the supposed difference in the periods of extinction of the Palæozoic brachiopods in the Himálayas and in the Salt Range has no solid foundation whatever. But even if the validity of this theory should be conceded, there was the error at the start that Noetling has mistaken synchronism for homotaxis. It is on homotaxis, however, not on synchronism, that all stratigraphical correlation must needs be based.

With this negative evidence of the absence of Palæozoic brachiopods the positive evidence of a faunula of Triassic lamellibranchs agrees. From the unquestionable affinity or even identity of some *Ammonoidea* and *Lamellibranchiata* in the Indian *Otoceras* fauna with species of the American *Meekoceras* and of the Alpine *Seis* beds, there is scarcely room to doubt that the *Otoceras* stage is, indeed, of *Triassic* age.

We are led to the same conclusion by the method of comparing the Permo-Triassic sequence of the Himálayas with that of the Eastern Alps, where, exactly as in India, the gap between the two systems is filled up by an uninterrupted series of marine deposits, ranging from the Groeden sandstones into the Werfen beds without the slightest trace of an unconformity. The Permian age of the Alpine Bellerophon Limestone having been ascertained, the question arises, whether it should be correlated with the Kuling shales and Upper *Productus* Limestone or with the *Otoceras* beds.

Such faunistic affinities as exist between the *Otoceras* beds and the corresponding Alpine deposits point in the direction of the *Seis* beds, not of the Bellerophonkalk, as has been demonstrated by Bittner.

One species of *Bellerophon* (*B. cf. Vaceki* Bittn.) is probably identical. Among three species of lamellibranchs two are allied very closely to types from the Seis beds, *Pseudomonotis* (*Claraia*) *Griesbachi* Bittn. to *Claraia ovata* Schaur., and a species of *Avicula* to the common *A. Venetiana* v. Hauer. Brachiopoda of Palæozoic habit have not been met with either in the Otoceras beds or in the Seis beds. Their only representative in the Otoceras beds, *Norella procreatrix* Bittn., belongs to a group or subgenus which is at present known only from Triassic rocks.

On the other hand the recent discoveries of Kossmat and Schellwien in Carniola clearly prove the Productus Limestone of the Salt Range to be the Indian representative of the Bellerophonkalk. The faunula from the hills to the west of Laibach exhibits striking affinities with the Permian faunæ of the Punjab. From this locality the following species have been quoted by Schellwien¹ :—

Richthofenia aff. *Lawrenciana* de Kon.

Productus indicus Waag.

„ *Abichi* Waag.

Marginifera ovalis Waag.

Lonsdaleia indica Waag. et Wentz.

The discovery of this fauna excludes any possibility of correlating the Bellerophonkalk with the Ceratite formation or with the Otoceras beds. The homotaxis of the Bellerophonkalk with the Ceratite formation has been advocated recently by G. Caneva.² This author admits the existence of faunistic affinities between the Bellerophonkalk and the Productus Limestone, but considers them to be too small to justify a homotaxis of the two groups. He prefers to correlate the Bellerophonkalk with the Ceratite formation, to which no faunistic affinities whatever exist. This is one of the most instructive illustrations of a method of correlation founded on wrong principles.

The only ammonite hitherto known from the Bellerophon limestone, *Paralecanites sextensis* Dien.³ belongs to a genus which has also

¹ E. Schellwien : *Monatsber. d. Deutschen Geol. Ges.*, 1905, p. 35 f.

² G. Caneva : Ueber die Bellerophonkalk fauna. Zur Frage der Perm-Triasgrenze *Neues Jahrb. f. Mineral, etc.*, 1906, II, pp. 52-60.

³ C. Diener : Ueber ein Vorkommen von Ammoniten und Orthoceren im sued-tirolischen Bellerophonkalk, *Sitzgsber. kais. Akad. d. Wissensch.*, CVI, 1897, Math Nat. Kl. p. 66.

been found in the *Meekoceras* beds of Idaho associated with a typical Lower Triassic fauna. But the American species, *P. Arnoldi* Hyatt et Smith,¹ is not identical with the Alpine form. The two distinguished authors are probably right in regarding it as a survival of the ancestral type, whose mature form is very much like the larval stages of *Meekoceras*.

I may be permitted to quote in this place a note from my memoir on the Permian fossils of the Central Himálayas (*Palæont. Ind.*, ser. XV., Himál. Foss., Vol. I, Pt. 5, p. 196):—

“A bed of peculiar interest is the Permian limestone, which south of Pomarang, is intercalated in the dark micaceous Kuling shales. It is rich in gasteropods and bivalves, and recalls the *Bellerophon* limestone of the South-eastern Alps. With the fauna of this remarkable horizon it has probably one species, *Bellerophon Vigilii* Stache, in common. The predominance of European Permian types in this limestone is an interesting fact. Three species of bivalves—*Modiolopsis Teploffii* Vern., *Solemya biarmica* Vern., *Oxytoma latecostatum* Netsch.—are identical with such from the Permian strata of Russia, whereas another one is most nearly allied to *Conocardium siculum* Gemm., from the Permian *Fusulina* limestone of Sosio in Sicily.”

Any attempt to include the *Otoceras* stage in the Permian system is contradictory to palæontological evidence. It necessitates a correlation of the *Otoceras* beds with the *Bellerophonkalk*, to which their fauna has no affinity.

On the principle of establishing correlation of horizons in distant countries by identity of the fossils all the evidence goes to prove that the *Bellerophonkalk* is the homotaxial equivalent of the Upper *Productus* Limestone and of the Kuling shales, especially of the limestone of Pomarang containing *Bellerophon Vigilii*, whereas the *Otoceras* stage corresponds stratigraphically to the lowest division of the Werfen beds (lower Seis beds).

¹ A. Hyatt and J. P. Smith: Triassic cephalopod genera of America, l. c., p. 136.

The following table shows this correlation of Permo-Triassic beds in the Eastern Alps and in India :—

	Eastern Alps.	Salt Range.	Himálayas.
Buntsand- stein	Campil beds	Upper Ceratite limestone. Ceratite sandstones Ceratite marls	Zone of <i>Sibirites spiniger</i> . Hedenstrœmia beds. Meekoceras beds.
(Seythian stage.)	Seis beds with <i>Claraia</i> sp., <i>Bellerophon Vaceki</i> , etc.	Lower Ceratite lime- stone. Unfossiliferous beds in the section of Chideru.	Otoceras beds with <i>Claraia</i> sp., <i>Avicula</i> aff. <i>Uenetiana</i> , <i>Bellerophon</i> cf. <i>Vaceki</i> .
Upper Permian.	Bellerophonkalk, with <i>Productus indicus</i> , <i>P. Abichi</i> <i>Bellerophon Vigili</i> , etc.	Upper Productus limestone.	Kuling shales (lime- stone of Pomarang with <i>Bellerophon</i> <i>Vigili</i>).

On considering these several facts, I have been confirmed in my view published in 1897, that the Otoceras beds of the Himálayas must be included with the Lower Trias and that the boundary between the Permian and Triassic systems must be drawn between the Otoceras beds and the Kuling shales in the Himálayas, between the Chideru stage of the Upper Productus Limestone and the Lower Ceratite Limestone in the Salt Range, between the Bellerophonkalk and the lower Werfen beds (Seis beds) in the Eastern Alps.

II. THE MIDDLE TRIAS.

(Muschelkalk and Ladinic stage.)

a. *The Muschelkalk of Spiti and Painkhanda.*

There is an almost perfect identity in the development of the Muschelkalk in Spiti and Painkhanda, although it has taken a considerable time to establish this fact with full certainty. A. v. Krafft was the first to draw attention to this uniform development,

which goes so far that almost every single bed found in the one area can be recognised in the other, as will be seen from a comparison of the section near Lilang with that of the Bambanag cliff.

The section observed by A. v. Krafft and H. Hayden near Lilang in Spiti is as follows (in descending order):—

- | | | | |
|-----|--|-----------|----------|
| 4. | Dark grey limestone, often concretionary, with shaly partings. Upper Muschelkalk | | 22 feet. |
| 3 f | Grey limestone with <i>Ceratites Ravana</i> | | 16 ins. |
| 3 e | Grey concretionary limestone | | 6 ins. |
| 3 d | Shales with <i>Spiriferina Stracheyi</i> | | 4 ins. |
| 3 c | Grey limestone | | 3 ins. |
| 3 b | Hard, grey limestone with <i>Keyserlingites Dieneri</i> | | 4 ins. |
| 3 a | Thin layers of grey limestone and shale | | 3 feet. |
| 2. | Nodular limestone (Niti limestone Noetl.) | | 60 feet. |
| 1. | Shaly limestone with <i>Rhynchonella Griesbachi</i> | | 3 feet. |

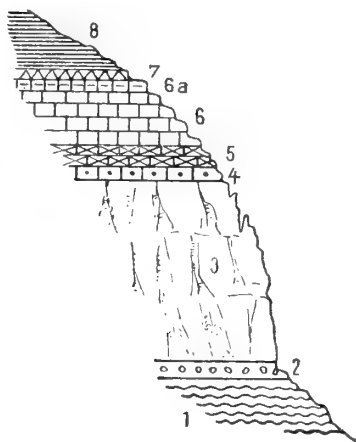


FIG. 2. Section through the Middle Trias along the Lingti river (from A. v. Krafft's diary).

8. *Daonella* shales, with *Daonella Lommeli*.
7. Passage beds.
6. Upper Muschelkalk.
- 6a Main layer of *Ptychites rugifer*.
5. Zone of *Spiriferina Stracheyi*.
4. Zone of *Keyserlingites Dieneri*.
3. Nodular limestone.
2. Limestone with *Rhynchonella Griesbachi*.
1. *Hedenstrœmia* beds.

At the Bambanag cliff the following section was observed by A. v. Krafft in 1900 :—

- | | | |
|-----|--|----------|
| 4. | Upper Muschelkalk with numerous specimens of <i>Ptychites</i> ,
<i>Hollandites</i> , <i>Beyrichites Khanikoffi</i> Opp., <i>Gymnites Vasan-
tasena</i> , Dien, etc. | 20 feet. |
| 3 i | Shales with many concretions, containing <i>Spiriferina
Stracheyi</i> | 2 feet. |
| 3 h | Dark grey limestone with <i>Spiriferina Stracheyi</i> and <i>Spiri-
gera Stoliczkai</i> | 1 foot. |
| 3 g | Black shales | 5 ins. |
| 3 f | Dark grey limestone with <i>Keyserlingites Dieneri Monophyllites Hara</i> , <i>M. Kingi</i> , <i>Spiriferina Stracheyi</i> , <i>Spirigera
Stoliczkai</i> | 5 ins. |
| 3 e | Black shale | 2 ins. |
| 3 d | Limestone as 3 f containing <i>Gymnites sp.</i> | 7 ins. |
| 3 c | Black shales | 5 ins. |
| 3 b | Limestone as 3 h with <i>Monophyllites sp.</i> and <i>Dalmatites
Ropini</i> Dien. | 6 ins. |
| 3 a | Black shales with <i>Keyserlingites sp.</i> | 5-6 ins. |
| 2. | Nodular limestone (Niti limestone Noetl.) unfossilif-
erous | 50 feet. |
| 1. | Earthy limestone with <i>Rhynchonella Griesbachi</i> and <i>Retzia
himaica</i> | 3 feet. |

In geological delimitation the Muschelkalk begins with the basal limestone No. 1. In biological definition the first marine fauna of a typical character is that included in the shales and limestones No. 3. The overlying dark grey and well-bedded limestones (No. 4) have yielded a large number of *Cephalopoda*.

The difference between the faunæ contained in the two subdivisions Nos. 3 and 4 gave occasion for drawing the boundary line between the Lower and Upper Muschelkalk at the top of No. 3. The massive nodular limestone No. 2 is practically unfossiliferous, but is very conspicuous in the scenery, towering in a steep escarpment above the slope of the Lower Triassic beds. For this horizon the name of Niti limestone was suggested by Noetling.

This fourfold division of the Muschelkalk has also been observed in the section of the Shalshal cliff by A. v. Krafft, where he distinguished the following groups (in descending order) :—

4. Upper Mulchelkalk very rich in ammonites.
- 3 b Thin beds of limestone with the brachiopod fauna of *Spiriferina Stracheyi*.

- 3 a Shaly limestone with *Keyserlingites Dieneri*.
 2. Nodular limestone, unfossiliferous.
 1. Earthy limestone, with *Rhynchonella Griesbachi* and *Betzia haimica*.

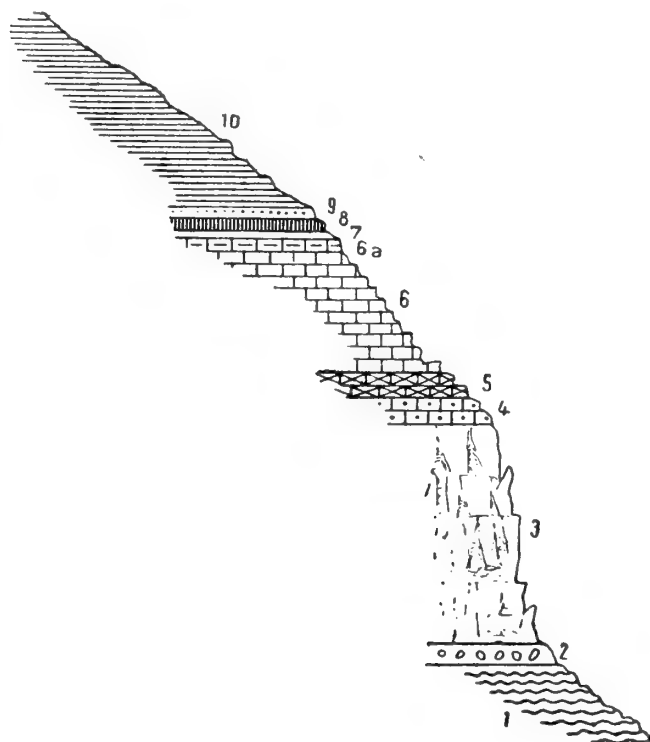


FIG. 3. Section through the Middle Trias of the Shalshal cliff, opposite Rimkin Puär.

10. Shales with *Halobia comata*.
9. Shaly limestone with *Daonella indica*.
8. Traumatocrinus limestone.
7. Passage beds (ladinic stage).
6. Upper Muschelkalk.
- 6 a Main layer of *Ptychites rugifer*.
5. Thin beds of limestone with *Spiriferina Stracheyi*.
4. Shaly limestone with *Keyserlingites Dieneri*.
3. Nodular limestone (Niti limestone).
2. Limestone with *Rhynchonella Griesbachi*.
1. Hedenstroemia beds.

The recognition of these four subdivisions in the section of the Shalshal cliff settles for us several disputed questions, for this section

had furnished the basis for the classification of the Muschelkalk by Griesbach and Diener in which they had been particularly unfortunate.¹

Those two authors distinguished a thin lower division with *Brachipoda* (*Rhynchonella Griesbachi*), corresponding to No. 1, and a thick upper division, corresponding to beds Nos. 2, 3, 4 in A. v. Krafft's classification, but did not appreciate the stratigraphical importance of the horizon No. 3, because the fossils from it became mixed up with those of other horizons in the collections made by the expedition in 1892. Thus two different brachiopod faunæ were included in Diener's list of species from bed No. 1, the fauna of *Rhynchonella Griesbachi* which actually belongs to this horizon, and the fauna of *Spiriferina Stracheyi*, which has its habitat in the shaly beds (No. 3) above the Niti limestone.²

This mistake was combined with a second one from which considerable confusion arose. It was the supposed discovery of a specimen of *Keyserlingites* (group of *Ceratites subrobusti* Mojs.) in the Hedenstrœmia beds, for which, consequently the name "Subrobustus beds" was then proposed by Diener. Since the actual layer of this ammonite was fixed in the beds with *Spiriferina Stracheyi* by A. v. Krafft, not in the upper division of the Lower Trias, as suggested by Diener, the name "Subrobustus beds" had to be dropped afterwards.

The two brachiopod faunæ of the zones of *Rhynchonella Griesbachi* and *Spiriferina Stracheyi* (beds Nos. 1 and 3) were first distinguished by A. Bittner,³ but his view only depended upon palæontological evidence. Their existence was, however, soon afterwards confirmed by geological researches, thus proving the fact that the testimony of fossils can always be relied on to the extent and precision which a palæontologist's ability to interpret them will permit.

In 1899 A. v. Krafft⁴ ascertained the presence of the brachiopod-bearing horizon with *Spiriferina Stracheyi* Salt. in Spiti between the underlying mass of the Nodular limestone (Niti limestone) and the

¹ *Jahrb. k. k. Geol. Reichsanst.*, 1899, p. 692.

² In the classification adopted by the Geological Survey of India, this is known as the "Nodular limestone" (see Burrard and Hayden, *Geography and Geology of the Himalaya and Tibet*, p. 239).—EDITOR.

³ C. Diener: *Ergebnisse einer geologischen Expedition in den Central-Himalaya*, *Denkschr. kais. Akad.*, LXII, 1895, pp. 571, 572.

⁴ *General Report, Geol. Surv. of India for 1899-1900*, p. 202.

Upper Muschelkalk, and discovered the bed No. 3, containing *Keyserlingites Dieneri* Mojs. (*Ceratites subrobustus* antea). In 1900 he fixed the horizons distinguished by the two brachiopod faunas in the Bambanag and Shalshal cliffs, showing that the upper one (bed 3) was characterised by *Spiriferina Stracheyi*, and the lower one (bed 1) by *Rhynchonella Griesbachi*.

In Spiti this question was finally settled by H. Hayden's discovery of the layer with *Rhynchonella Griesbachi* at the base of the Nodular limestone, in the exact position in which it had been found in the Bambanag and Shalshal cliffs by Griesbach, Diener and A. v. Krafft.²

The evidence now available enables us to point out exactly where to draw the stratigraphical lines to indicate the four subdivisions which can be distinguished in the Muschelkalk in Painkhanda and Spiti, but the position of the two lower subdivisions in the general standard of the Triassic system is not quite clear.

The age of the bed with *Rhynchonella Griesbachi* (No. 1) and of the Nodular limestone (No. 2) is looked upon as doubtful by Hayden and A. v. Krafft. Noetling³ includes bed No. 1 with the Hedenströemia stage of the Lower Trias and bed No. 2 (his Niti limestone) with the Muschelkalk.

From the horizon of *Rhynchonella Griesbachi* three species of *brachiopoda* are known, namely :—

Rhynchonella Griesbachi Bittn.

Norella Kingi Bittn.

Retzia himaica Bittn.

Although *Rhynchonella Griesbachi* belongs to the Alpine group of *Rh. trinodosi* Bittn. which is one of the chief leading fossils of the Muschelkalk, its presence cannot be regarded as a sufficient proof in favour of a Muschelkalk age of this horizon.

Diener records one ammonite from the layer with *Rhynchonella Griesbachi*, *Sibirites Prahlada*, which he claims to have chiselled out from

¹ General Report, Geol. Surv. of India for 1900-01, p. 26. Zur Gliederung des Muschelkelkes im Himalaya, Verhandl. k. k. Geol. Reichsanst., 1901, p. 52.

² H. Hayden : The Geology of Spiti, l. c., p. 69.

³ Asiatische Trias, *Lethæa mesozoica*, l. c., pp. 138, 139.

the rocks *in situ* in a section of the Shalshal cliff, not locally identical with the section where the large species of brachiopods from the zone of *Spiriferina Stracheyi* have been found.¹ In Spiti, however, several examples of this species have been collected in bed 3b of the section near Lilang by A. v. Krafft.² Now the question arises, whether *Sibirites Prahlada* is restricted to bed 3 or ranges from the layer with *Rhynchonella Griesbachi* into a horizon of undoubted Muschelkalk age. No second specimen has been found in Painkhanda, neither in bed 1, nor in bed 3 of the Bambanag and Shalshal cliffs.

Provided the species could be proved to have its habitat in bed No. 1 of the Shalshal cliff, this might be accepted as a strong reason for including the horizon of *Rhynchonella Griesbachi* with the Muschelkalk.

On the other hand two ammonites, which have been discovered in the Niti³ limestone of Spiti by H. Hayden, were identified with species from the Hedenstroemia beds of Muth by A. v. Krafft.⁴ He therefore proposes to draw the boundary line between the Lower and Middle Trias at or above the middle of the Niti limestone. But Diener, on the strength of a re-examination of the specimens collected by Hayden, refuses to admit their identity with Lower Triassic species declaring them to be altogether indeterminable owing to their unfavourable state of preservation.⁵

In the absence of more convincing evidence, the age of the bed containing *Rhynchonella Griesbachi* and of the overlying Niti limestone must still remain an open question. For the present I prefer to leave them with the Muschelkalk, both from respect for historical priority—Griesbach having included them in the Upper Trias—and because from a geological point of view the Niti limestone certainly belongs to this group, not to the Lower Trias.

¹ C. Diener : The fauna of the Himálayan Muschelkalk, *Palaeont. Ind.*, Ser. XV, Vol. V, Pt. 2, p. 130.

² The name 'zone of *Sibirites Prahlada*,' in the sense in which it was used by Diener must be discarded, since this species has in Spiti its main layer above, not below the Niti limestone.

³ See footnote to p. 59.—ED.

⁴ H. Hayden, *Geology of Spiti*, l. c., p. 67.

⁵ In *General Report, Geol. Surv. of India*, 1899-1900, p. 192, H. Hayden mentions one species of *Nautilidæ*, *Grypoceras sp. ind. ex. aff. Palladii* Mojs. from the Niti limestone of Spiti.

Leaving aside the horizon of *Rhynchonella Griesbachii* and the Niti limestone, which in thickness is the predominating element of the Middle Trias of Painkhanda, the rest of the Muschelkalk falls naturally into two subdivisions, a lower one about six feet in thickness, consisting of thin-bedded, grey limestones, partly alternating with shales (bed No. 3), and a higher one (No. 4) reaching a thickness of 20 feet, consisting of dark grey, regularly bedded limestones. In the scenery the group No. 3 is often indicated by a softer slope, interrupting the outlines of the steep escarpments above and below.

The Lower Muschelkalk (group No. 3) constitutes one single stratigraphical horizon. There is no definite boundary between the lower beds containing ammonites and the higher ones containing brachiopods. As we pass upwards in the sections—especially in that of the Bambanag cliff,—the ammonites are gradually replaced by brachiopods, according to A. v. Krafft's observations. The whole series between the Niti limestone and the Upper Muschelkalk must therefore be united in one group, but it must be understood that the cephalopoda prevail in the lower part of the group, and the brachiopoda in the upper.

The brachiopod fauna of the zone of *Spiriferina Stracheyi* is very uniform in Painkhanda and Spiti. From both regions the following three species are known:—

Spiriferina Stracheyi Salt.

Spirigera Stoliczkai Bittn.

Rhynchonella Dieneri Bittn.

A fourth species, *Rhynchonella mutabilis* Stol., is hitherto known from Spiti only. Three other species of brachiopods, which have been described by Stoliczka in volume V of the *Memoirs of the Geological Survey of India*, are of doubtful position, since it is uncertain whether they belong to the Lower or to the Upper Muschelkalk.

Regarding the cephalopod-fauna of the Lower Muschelkalk, the Spiti sections—especially those of Lilang and along the Gyundi river—have yielded a considerably larger number of fossils than the sections of Painkhanda.

The following four species, all of which were collected by A. v. Krafft and Hayden, are common to both districts:—

Keyserlingites Dieneri Mojs.

Dalmatites Ropini Dien.

Monophyllites Hara Dien.

„ *Kingi* Dien.

Twelve species are peculiar to Spiti, namely :—

Ceratites (Hollandites) Vyasa Dien.

„ *(Danubites) cf. Kansa* Dien.

Keyserlingites Pahari Dien.

„ *pagoda* Dien.

„ *sp. ind. aff. Bungei* Mojs.

Japonites cf. Ugra Dien.

Stacheites Webbianus Dien.

Sibirites Prahlada Dien.

Gymnites depauperatus Dien.

„ *sp. ind. aff. Sankara* Dien.

Monophyllites (Mojsvarites) Confucii Dien.

„ „ *Pradyumna* Dien.

Only two species of *Nautiloidea* which appear in A. v. Krafft's collections from the Shalshal cliff have not as yet been noticed in the Lower Muschelkalk of Spiti. Those species are :—

Orthoceras cf. multilabiatum Hauer.

„ *cf. campanile* Mojs.¹

The most characteristic element in this fauna is the group of *Keyserlingites Dieneri* (*Ceratites subrobusti*).

The Himálayan representatives of this group are not identical with those from the Olenek beds of Siberia. It might even be questioned whether they should actually be included in the genus (or subgenus) *Keyserlingites*. They serve indeed to illustrate one of the most interesting cases of convergence. Full grown individuals of *Keyserlingites Dieneri* agree so closely with the Siberian *Keyserlingites subrobustus* Mojs. in all their external characters, that their examination did not lead to the discovery of any features which might justify a specific separation. It was only the examination of inner nuclei—not known before 1905—which showed the larval and adolescent stages to differ remarkably from the corresponding stages in *Keys. subrobustus*. Whereas inner nuclei of the latter species resemble mature stages of *Dinarites (Olenekites)*

¹ All the species quoted in this list have been described and illustrated in Diener, Fauna of the Himálayan Muschelkalk, *Pal. Ind.*, ser. XV, Vol. V, Pt. 2.

spiniplicatus, its Indian representative passes through stages resembling *Tirolites* and afterwards *Sibirites*.

There is consequently no real affinity between the Indian and Siberian types corresponding to their astonishing resemblance in external shape, sculpture and sutures. A new subgeneric denomination, *Durgaites*, might be proposed for the Himálayan forms.

The Upper Muschelkalk (No. 4) is a cephalopod-facies, in which very few remains of *Brachiopoda*, *Gastropoda* and *Lamellibranchiata* are associated with a large number of ammonites. The following species of *Brachiopoda* certainly belong to the Upper Muschelkalk of Spiti :—

Coenothyris vulgaris Schloth.

Mentzelia Mentzelii Dunk.

„ *kæveskaliensis* Suess.

The following species of *Gastropoda* and *Lamellibranchiata* must be added to this list :—

Pleurotomaria indica Blaschke.

Worthenia Dieneri Blaschke.

Tectospira gracilis Blaschke.

Omphaloptycha sp. ind.

Pseudomelania sp. ind.

Cardiomorpha (?) *Haydeni* Dien.

Lima sp. ind. aff. *lineata* Desh.

Posidonomya sp. ind. aff. *pannonica* Mojs.

The differences between the cephalopod faunæ of Spiti and of Painkhanda are of small importance. In both areas the fauna of the Upper Muschelkalk is richer in species than that of any other Triassic horizon. Not less than 23 species of *Cephalopoda* are common to the two districts, among them all the important leading fossils of this horizon. These species are :—

Ceratites Thuilleri Opp.

„ *Kamadeva* Dien.

„ (*Hollandites*) *Voiti* Opp.

„ „ *Ravana* Dien.

„ „ *Airavata* Dien.

„ „ *Visvakarma* Dien.

„ „ *Dungara* Dien.

Ceratites (Hollandites) Moorei Dien.

„ „ *Vyasa* Dien.

„ „ *Cecilii* Dien.

Beyrichites Khanikoffi Opp.

„ *Kesava* Dien.

Acrochordiceras Balarama Dien.

Sturia Sansovinii Mojs.

Buddhaites Rama Dien.

Gymnites Jollyanus Opp.

„ *Sankara* Dien.

Ptychites rugifer Opp.

„ *cochleatus* Opp.

„ *Everesti* Opp.

„ *Gerardi* Blfd.

„ *Sumitra* Dien.

„ *Mahendra* Dien.

The following 44 species of *Cephalopoda* are confined to Spiti :—

Orthoceras spitiense Dien.

Mojsvaroceras kagæ Dien.

Germanonutilus cf. salinarius Mojs.

Syringonutilus spitiensis Stol.

Grypoceras Griesbachi Dien.

Paranutilus Bullockii Dien.

Ceratites trinodosus Mojs.

„ *himalayanus* Blfd.

„ *sp. ind. ex. aff. Abichi* Mojs.

„ *superbiformis* Dien.

„ *truncus* Opp.

„ *Devasena* Dien.

„ *Padma* Dien.

„ (*Hollandites*) *Hidimba* Dien.

„ (*Salterites*) *Oberhummeri* Dien.

„ (*Haydenites*) *Hatschekii* Dien.

Beyrichites proximus Opp.

Cuccoceras yoga Dien.

Japonites cf. Dieneri Mart.

Isculites Hauerinus Stol.

Acrochordiceras cf. Carolinæ Mojs.

Acrochordiceras sp. ind. aff. *pusterico* Mojs.

Monophyllites sphærophyllus Hauer.

Pinacoceras Rajah Dien.

Gymnites incultus Beyr.

„ cf. *Humboldti* Mojs.

„ *Mandiva* Dien.

„ *Kirata* Dien.

„ *religiosus* Dien.

„ sp. ind. aff. *subclausus* Hauer.

Anagymnites Lamarcki Opp.

„ cf. *acutus* Hau.

„ *Torrensii* Dien.

Ptychites cognatus Opp.

„ *Sukra* Dien.

„ *Asura* Dien.

„ *Durandii* Dien.

„ *Vidura* Dien.

„ *Malletianus* Stol.

„ *impletus* Opp.

„ *Mangala* Dien.

Joannites cf. *proavus* Dien.

Proarcestes Baljouri Opp. (= *Escheri* Mojs.)

„ sp. ind. aff. *Bramantei* Mojs.

The following thirteen species are restricted to Painkhanda according to the present state of our knowledge :—

Ceratites Royleanus Dien.

„ *Arjuna* Dien.

„ (*Gymnotoceras*) aff. *geminato* Mojs.

„ (*Hollandites*) *Nalikanta* Dien.

„ „ *Srikanta* Dien.

„ „ *Narada* Dien.

Ananorites monticola Dien.

Japonites Sugriva Dien.

„ *Chandra* Dien.

Beyrichites Gangadhara Dien.

„ *affinis* Mojs.

„ *Rudra* Dien.

A faunula of the Upper Muschelkalk of a rather peculiar character was collected by Diener on the southern slope of the Uttardhura leading from Milam (Johar) to the Girthi valley (Painkhanda). The three following species are peculiar to this locality and have not been found in the sections of Painkhanda and Spiti :—

Orthoceras cf. campanile Mojs.

Acrochordiceras joharensense Dien.

Pseudodanubites Dritarashtra Dien.

An exposure of Muschelkalk, probably rich in beautifully preserved fossils, but not yet examined thoroughly, was discovered by Griesbach on the eastern slope of the Tsang Tsok La (Hop Gád) in Hundes. It has yielded the following species :—

Ceratites (Hollandites) Hidimba Dien.

Beyrichites Khanikoffi Opp.

Ptychites Govinda Dien.

Proarcestes Balfouri Opp.

In general the fauna of the Upper Muschelkalk is very uniform in Painkhanda and Spiti. The number of species peculiar to either of the two districts will no doubt be reduced still more considerably by future researches.

b. The Muschelkalk of Kashmir.

The presence of Muschelkalk in Kashmir is proved by a small number of ammonites and brachiopods, collected by Prochnow, the brothers von Schlagintweit, Stoliczka and Lydekker.

Spiriferina Stracheyi Salt. from the Tsarap valley (Zaskar basin) points to the lower division of the Muschelkalk (group No. 3).

The fauna of the Upper Muschelkalk is indicated by *Ceratites Thuilleri* (Sonamarg), *Gymnites Salteri* Beyr. (Ladakh, exact locality not known), *Proarcestes Balfouri* Opp. (= *Escheri* Mojs.) from Dras (50 to 60 miles E. N. E. of Srinagar), *Ptychites Durandii* Dien. from Padam (Zaskar valley).¹

In the sections of the Guryul ravine the Muschelkalk is represented by sandy shales with subordinate limestones, which follow conformably above the Lower Trias. In the middle division of this group

¹ *Palæont. Indica*, ser. XV, Vol. V, Pt. 2, p. 139.

Rhynchonella cf. trinodosi Bittn., *Rh. cf. mutabilis* Stol. and *Spiriferina Stracheyi* Salt. have been collected by C. S. Middlemiss.

c. *The Muschelkalk of Eastern Johar.*

The development of the Muschelkalk in Eastern Johar agrees, as far as known, with that observed in Spiti and Painkhanda. The fossils, which have been collected from the ridge between the Dharma and Lissar valleys, are imbedded in a dark shaly limestone. Among the *Cephalopoda* the overwhelming majority are identical with species from the Shalshal cliff. The following species belong to the Upper Muschelkalk :—

- Grypoceras sp. ind. ex. aff. Palladii* Mojs.
Ceratites Thuilleri Opp.
 „ (*Hollandites*) *Ravana* Dien.
 „ „ *Airavata* Dien.
 „ „ *Dungara* Dien.
Beyrichites cf. Rudra Dien.
Pseudodanubites cf. Dritarashtra Dien.
Acrochordiceras Balarama Dien.
 „ *cf. Carolinæ* Mojs.
 „ *sp. ind. aff. pusterico* Mojs.
Gymnites Sankara Dien.
 „ *Jollyanus* Opp.

The presence of the zone of *Spiriferina Stracheyi* is indicated by this species and by *Dielasma himalayanum* Bittn.

d. *The Muschelkalk of Byans.*

A. v. Krafft has drawn the attention of Indian geologists to the remarkable uniformity of the Muschelkalk in Spiti, Garhwal and Kumaon, a uniformity which goes so far that almost every single bed found in the one area can be recognised in the other. It seems, however, that a change takes place towards the east, for in Byans, in the north-eastern corner of Kumaon, near the boundary of Nepal, the Muschelkalk is developed in the facies of light grey limestone, without any trace of

shaly partings. This is evident from the notes left by Smith and A. v. Krafft, which have been published in my memoir on the fauna of the Himálayan Muschelkalk.

This eastern facies of the Himálayan Muschelkalk consists of pure limestones of a light grey colour, which overlie the chocolate limestone of Lower Triassic age. The dark, concretionary limestone with shaly partings, which is characteristic of the Muschelkalk in the north-western districts of the Central Himálayas, is entirely absent. In this development of light grey, pure limestones even the zone of *Rhynchonella Griesbachi* is included, as is proved by a large number of examples of this species in Smith's collections from Kalapani.

Noetling proposed to group the bed with *Rhynchonella Griesbachi* with the Hedenstrœmia stage, because in the section of the Shalshal cliff he found it to agree lithologically with this stage. Any geologist starting from an examination of the sections in Byans will be inclined to draw the boundary between the Lower and Middle Trias at the base, not at the top of the bed with *Rhynchonella Griesbachi*, which is united with the Muschelkalk into one uniform mass of light grey limestone.

The presence of the zone of *Spiriferina Stracheyi* is indicated by several species of brachiopods, characteristic of that zone, in Smith's collections from Jolinka and Kalapani, namely :—

Spiriferina Stracheyi Salt.

Spirigera Stoliczkai Salt.

Dielasma himalayanum Bittn.

It cannot be decided whether the two specimens of *Rhynchonella trinodosi* Bittn., one of the most characteristic species of the Alpine Muschelkalk, which I discovered among Smith's collections from Kalapani, have their habitat in this zone (group No. 3) or in the Upper Muschelkalk. The Indian group of *Ceratites subrobusti* (*Keyserlingites* Hyatt, *Durgaites* Dien.) is not yet known to us from Byans.

The layer of brachiopods, representing the zone of *Spiriferina Stracheyi* in the uniform mass of the Muschelkalk in Byans, occurs about 50 feet above the top of the chocolate limestone, according to A. v. Krafft. Thus the lower part of the Muschelkalk might be considered as an equivalent of the Niti¹ limestone in Painkhanda and Spiti. A bed of

¹ See footnote to p. 59.—Ed.

limestone, following above this brachiopod-layer, is rich in *Cephalopoda* of the Upper Muschelkalk. Fossils, which are as a rule strongly deformed and elliptical in outlines, have been found in considerable numbers near Kalapani (Griesbach) and Jolinka (Smith, A. v. Krafft).

The following species have been determined by Diener:—

- Atractites Smithii* Dien.
- Orthoceras cf. campanile* Mojs.
- Grypoceras Griesbachii* Dien.
- Mojsvaroceras sp. ind. aff. Morloti* Mojs.
- „ *nivicola* Dien.
- Ceratites Thuillieri* Opp.
- „ *Kuvera* Dien.
- „ (*Philippites*) *jolinkanus* Dien.
- „ (*Hollandites*) *Vyasa* Dien.
- „ „ *Roxburghii* Dien.
- „ (*Peripleurecyclus*) *Smithianus* Dien.
- Smithoceras Drummondii* Dien.
- Sageceras sp. ind.*
- Buddhaites Rama* Dien.
- Bukowskiites Colvini* Dien.
- Pinacoceras Loomisii* Dien.
- Gymnites Jollyanus* Opp.
- „ *Kirata* Dien.
- „ *Sankara* Dien.
- Ptychites Sahadeva* Dien.

This fauna, although showing unmistakably the character of the Upper Muschelkalk, is remarkable for the large number of types peculiar to this area. Not only the lithological, but also the faunistic development of the Muschelkalk in Byans is different from that of the north-western facies. Among twenty species of *Cephalopoda* not less than ten have not yet been found in any Himálayan district outside Byans. Some very remarkable types, as *Smithoceras*, *Philippites*, *Peripleurecyclus*, *Bukowskiites*, *Pinacoceras Loomisii* are represented among them. *Smithoceras Drummondii* deserves special interest, as the most primitive ancestor of the highly specialised types of *Haloritinæ* and *Juvavitinæ* in the Upper Trias.

Detailed researches will be necessary before anything more definite can be said about the Muschelkalk of Byans.

e. The Ladinic stage of Spiti.

One of the most important stratigraphical results of A. v. Krafft's and Hayden's researches in Spiti was the discovery of a very rich development of the Ladinic stage. The presence of this stage, which Diener and Griesbach had failed to recognise in the sections of the Bambanag and Shalshal cliffs, had been predicted by Bittner,¹ on the ground of his discovery of a specimen of *Daonella Lommeli* Wissm. among Griesbach's collections from Muth.

From H. Hayden's and A. v. Krafft's descriptions it is evident that no stratigraphical break occurs in Spiti above the Upper Muschelkalk, but that the passage into the ladinic stage is so gradual, that no boundary line can be fixed between the two. In the sections of Kágá, of Muth and in the Thanam valley, the topmost bed of the Muschelkalk group, which stratigraphically cannot be separated from the beds containing *Ptychites rugifer* Opp., has yielded a fauna of a decidedly ladinic aspect.

Above this passage bed follows a series of thin-bedded black, shaly limestones and earthy shales, with some hard, black limestone beds (weathering brown), of 160 feet in thickness. This is the group of 'Daonella shales,' the prototype of the ladinic stage in Spiti.

The fauna of the passage beds in Spiti consists of the following species :—

Spirigera hunica Bittn.

Ceratites (?) *Wetsoni* Opp.²

Arpadites cf. *lissarensis* Mojs.

„ *rimkinensis* Mojs.

Hungarites Pradoi d'Arch.

„ *sp. ind. aff. Mojisisovicsi* Bœckh.

Protrachyceras longobardicum Mojs.

„ *spitiense* Dien.

„ *Cautleyi* Dien.

¹ A. Bittner, *Palæont. Indica*, ser. XV, Himálayan Foss., Vol. III, Pt. 2, p. 38.

² The appurtenance of this species to the genus *Ceratites* is extremely doubtful.

Thanamites bicuspidatus Dien.

„ *bannaensis* Dien.

Rimkinites nitiensis Mojs.

„ *Edmondii* Dien.

Sturia sp. ind.

Ptychites Gerardi Blanf.

Megaphyllites Jarbas Muenst.

Joannites Kossmati Dien.

„ cf. *proavus* Dien.

Proarcestes cf. *Balfouri* Opp.

This fauna has ten species in common with the *Daonella* shales and three only with the Upper Muschelkalk. All of them—*Ptychites Gerardi*, *Joannites* cf. *proavus*, *Proarcestes Balfouri*—range from the Upper Muschelkalk into the *Daonella* shales. The topmost bed of the Muschelkalk group must, consequently, be included in the ladinic stage.

All the sections in Spiti examined by H. Hayden and A. v. Krafft, prove that there is a gradual passage both lithologically and faunistically from the Upper Muschelkalk into the ladinic stage. The typical fauna of the latter stage is concentrated in the *Daonella* shales near the base of which the following species have been found :—

Daonella Lommeli Wissm.

„ sp. ind. aff. *Lommeli* Wissm.

„ *indica* Bittn.

Spirigera hunica Bittn.

Rhynchonella cf. *Theobaldiana* Stol.

Ceratites Narsingha Dien.

Arpadites rimkinensis Mojs.

Hungarites Pradoi d'Arch.

Thanamites bicuspidatus Dien.

Rimkinites nitiensis Mojs.

„ *Edmondii* Mojs.

Analcites Laczkoi Dien.

Protrachyceras Archelaus Lbe.

„ *spitiense* Dien.

„ *ladinum* Mojs.

„ cf. *longobardicum* Mojs.

„ sp. ind. cf. *regoledanum* Mojs.

- Sturia* sp. ind.
Gymnites calosoma Dien.
Pinacoceras sp. ind. aff. *Damesi* Mojs.
Ptychites Gerardi Blfd.
Joannites cf. *proavus* Dien.
 ,, sp. ind. cf. *tridentinus* Mojs.
 ,, *Kossmati* Dien.
Proarcestes bicinctus Mojs.
 ,, cf. *Balfouri* Opp.
 ,, sp. ind. aff. *esinensi* Mojs.

This fauna clearly bears the stamp of ladinic age, as shown by the relationship of a large number of species to European ones. *Daonella Lommeli*, the leading fossil of the ladinic stage in the Tyrol (Wengen beds) occurs throughout the entire thickness of the *Daonella* shales.

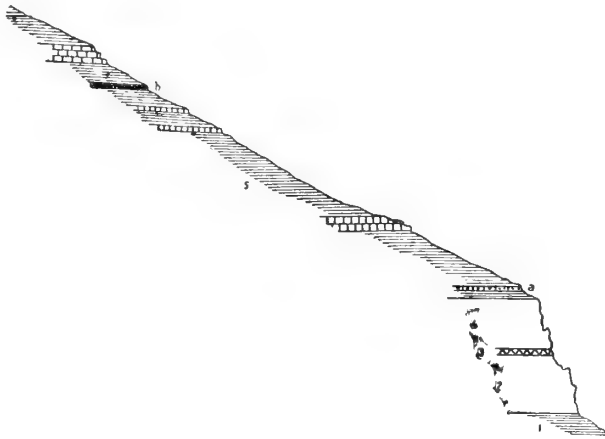


FIG. 4. Detailed section through the upper ladinic and lower carnic beds near Lilang from A. v. Kraft's diary :—

5. Grey beds (shales alternating with limestones).
4. Halobia limestone.
3. Horizon of *Joannites thanamensis*.
2. *Daonella* limestone.
1. *Daonella* shales, with *Daonella Lommeli*.

The *Daonella* shales are overlain by a homogeneous mass of dark, plintery limestone, about 280 feet in thickness. This mass is divided by a band of black limestone intercalated with shales. The lower

division contains *Daonella indica* Bittn., and, in its lower part, als *Daonella Lommeli*, whereas in the upper region *Halobia cf. comata* Bittn., a species of the carnic group of *rugosæ*, has been found.

A. v. Krafft, who designated the lower division as "*Daonella limestone*" and the upper as "*Halobia limestone*," gives the following sequence of beds between the Upper Muschelkalk, and the grey shales with *Joanites cymbiformis*¹ :—

4. Hard, black, splintery limestone, somewhat bituminous, with calcite veins, weathering greyish brown, intercalated with shaly limestones in layers of one to three feet containing *Halobia cf. comata* Bittn., and *H. fascigera* Bittn. 111 ft.
3. Black limestones, intercalated with shales containing *Joannites thanamensis* Dien. 25 ft.
2. Hard black limestones, as 4 with *Daonella indica* Bittn. *Daonella Lommeli* occurs in the lower division, but not higher up than to the upper third of this group . . . 145 ft.
1. Series of thin-bedded black shales and limestones (*Daonella* shares) with *Daonella Indica* Bittn. and *D. Lommeli* Wissm. 160 ft.

Series No. 2 corresponds to A. v. Krafft's "*Daonella limestone*." It contains a fauna consisting of the following species :—

- Traumatocrinus sp. ind.*
Daonella Lommeli Wissm.
 „ *indica* Bittn.
 „ *sp. ind. aff. Cassianæ* Mojs.
Rhynchonella cf. rimkinensis Bittn.
Phloioceras deliciosum Dien.
Styrites lilangensis Dien.
Celtites trigonalis Dien.
 „ *perauritus* Dien.
Rimkinites nitiensis Mojs.
Monophyllites cf. wengensis Klipst.
Joannites cf. Klipsteini Mojs.
 „ *Kossmati* Dien.

In this fauna Wengen and St. Cassian types are associated so closely that both equivalents of the highest ladinic and of the lowest carnic beds of the Mediterranean regions seem to be represented in the *Daonella limestone* of Spiti.

¹ *General Report, Geol. Surv. of India, 1899-1900, p. 208.*

The entire thickness of the ladinic stage in Spiti undoubtedly exceeds that of the Muschelkalk considerably. If we include the lower half of the *Daonella* limestone (group 2 in the sequence as given above), in which *Daonella Lommeli* has been found ¹, it amounts to 240 feet. At any rate group No. 1, of 160 feet in thickness, is a typical representative of the ladinic stage in the Himálayas.

f. The Ladinic stage of Painkhanda, Johar and Byans.

In his description of the classical section of the Shalshal cliff Diener ² stated that the *Ptychites* beds of the Upper Muschelkalk were overlain by a series of well-bedded limestones of inconsiderable thickness, agreeing lithologically with the underlying Muschelkalk, and only distinguished from it by its abundance of crinoid stems (*Traumatocrinus* Dittm.).

The faunula of this *Traumatocrinus* limestone was declared by E. v. Mojsisovics to belong to the carnic stage (zone of *Trachyceras Aonoides*). From this Diener concluded that the ladinic stage and the zone of *Trachyceras Aon* (St. Cassian beds) were either missing from the Trias of the Himálayas or, if really present, were of such insignificant development and thickness, that they could not be separated from the Muschelkalk, much in the same way as they occur in the North-eastern Kalkalpen of Austria.

A. v. Krafft refused to admit the homotaxis of the *Traumatocrinus* limestone with the zone of *Trachyceras Aonoides*, but the recent examination of the rich fauna collected by him in the Bambanag and Shalshal cliffs has proved E. v. Mojsisovics' determination of its stratigraphical position to be entirely correct.

If there are, indeed, equivalents of the ladinic stage present in Painkhanda, they are very small in thickness and extremely poor in characteristic fossils. A. v. Krafft, when revising the sections in Painkhanda in 1900, found in the Shalshal cliff, between the highest beds of the Upper Muschelkalk containing *Ptychites rugifer* and the

¹ It has been demonstrated by Bittner (Himálayan Foss., l. c., Vol. III, Pt. 2, p. 34), that the true *Daonella Lommeli* is restricted to the ladinic stage of the Alpine Trias and does not ascend into higher stages (noric Hallstatt limestone) as has been suggested by Rothpletz.

² C. Diener, Ergebnisse einer geologischen Expedition in den Central Himálaya, etc., l. c., pp. 546, 547.

Traumatocrinus limestone, a series of thin-bedded concretionary limestone, with shaly partings, about 25 feet in thickness, which although agreeing lithologically with the Upper Muschelkalk, yielded a different faunula consisting of the following species :—

Daonella indica Dittn.

„ *cf. obliqua* Mojs.

Spirigera hunica Bittn.

Celtites cf. trigonalis Dien.

Joannites cf. proavus Dien.

There is only the presence of *Joannites cf. proavus* which can be urged in favour of a correlation with the ladinic stage. Otherwise the fauna is closely allied with that of the Traumatocrinus limestone. *Daonella Lommeli* the most important leading fossil of the Daonella shales of Spiti, is not yet known from any Triassic section in Painkhanda.

In the Bambanag cliff the Traumatocrinus limestone is also present, but beds to which a ladinic age might be assigned with any probability were not found there by A. v. Krafft.

There is, perhaps, an indication of the ladinic stage in the faunula of a dark grey limestone, which was discovered by C. L. Griesbach opposite the Ralphu glacier in the Lissar valley and designated by him “horizon of *Ammonites Aon.*” This faunula contains the following species :—

Daonella indica Bittn.

Arpadites lissarensis Mojs.

Protrachyceras ralphuanum Mojs.

Joannites sp. ind.

Ptychites Gerardi Blfd.

„ *posthumus* Mojs.

Although this fauna has an older aspect than that of the Traumatocrinus limestone, there is no direct proof of its ladinic age. It is too scanty and meagre to permit any definite statement, as it might be attributed to the ladinic or lower carnic stage with nearly equal reason.

In Byans there is no evidence whatever of a representation of the ladinic stage. It might be looked for in the uniform mass of light grey

limestones, which have yielded a fauna of Muschelkalk age in their lower, and the *Tropites* fauna in their upper, portions.

Thus we come to the following conclusions:—E. v. Mojsisovics and Diener were right in attributing the *Traumatocrinus* limestone to the carnic stage. Yet this limestone does not follow immediately above the *Ptychites* beds of the Muschelkalk, at least not in all sections of Painkhanda, but there is a small thickness of limestones, from which *Ptychites rugifer* is absent, intercalated between the Muschelkalk and the carnic stage. It is probably of ladinic age. There is no hiatus in the stratigraphy of the Himálayan Trias in the Shalshal cliff, but the ladinic beds, provided they are represented at all, are extremely reduced in thickness, lithologically identical with the Upper Muschelkalk, and at the same time very poor in characteristic fossils.

The ladinic stage is therefore of much less importance in the sections of Painkhanda than it is in Spiti. The black shales and limestones with *Daonella Lommeli*, which are 160 to 240 feet thick in Spiti and very rich in fossils, dwindle down towards the east until they are restricted to a few feet in the section of the Shalshal cliff. This is a very interesting fact. For while, as we have seen, the Muschelkalk is constant in thickness in the two areas, a remarkable change sets in during the ladinic stage. We shall see later on that this tendency of the Triassic deposits of the Himálayas to thin out towards the east, becomes still more marked in the Upper Trias.

g. Correlation of the Middle Triassic deposits of the Himalayas with those of Europe and America.

The similarity of the stratigraphical development of the Muschelkalk both in the Himálayas and the Eastern Alps is most striking, as has been stated by A. v. Krafft.

In both regions a thick mass of unfossiliferous limestones forms the basal division of the group. In the South-eastern Alps, more especially in the district of Recoaro, where the development of the Muschelkalk is more complete than anywhere else in the Mediterranean region, this mighty mass, which is very poor in fossils, corresponds to the limestone with *Dadocrinus gracilis*. It has yielded a few bivalves which are closely allied to Lower Triassic species from the Campil beds, but never any *Cephalopoda*. It is followed by a zone of marls and limestones rich

in brachiopods. The topmost bed contains ammonites of the zone of *Ceratites binodosus*. This is the fossiliferous horizon which in Alpine geological literature has often been designated as "Lower Muschelkalk," but lies proportionately high in the mass of the Alpine Muschelkalk. It is overlain conformably by the limestones of the Upper Muschelkalk containing the Cephalopod fauna of the zone of *Ceratites trinodosus*.

Each of those three divisions of the Alpine Muschelkalk might be compared to a corresponding division of the Muschelkalk group in the Central Hímalayas, the Niti¹ limestone, including the horizon of *Rhynchonella Griesbachi* at its base, to the limestone with *Dadocrinus gracilis*, the brachiopod-bearing beds with *Spiriferina Stracheyi* Salt. and the underlying horizon of *Keyserlingites (Durgaites) Dieneri* to the brachiopod-bearing zone of *Rhynchonella decurtata* and to the *binodosus* bed, the upper division with *Ceratites Thuillieri* and *Ptychites rugifer* to the cephalopod-bearing horizon of *Ceratites trinodosus*.

But as far as palæontological evidence goes, the correctness of this correlation, which is based on stratigraphical grounds, can only be proved for the upper division. In this division both the association of genera and the affinity or even identity of species indicate very close faunistic relations with the zone of *Ceratites trinodosus*.

Four species of *Brachiopoda* are identical, all of them representing very common and widespread types of the Alpine Muschelkalk, namely :—

Mentzelia Mentzelii Dunk.

Spiriferina Koeveskaliensis Suess.

Coenothyris vulgaris Schloth.

Rhynchonella trinodosi Bittn.

It must, however, be remarked that the exact layer of the last-mentioned species, which was collected from Kalapani in Byans by F. H. Smith, is not known exactly.

Among the class of *Cephalopoda* the following species are either directly or most probably identical with Alpine forms :—

Orthoceras campanile Mojs.

Germanonautilus cf. salinarius Mojs.

Ceratites trinodosus Mojs.

¹ See footnote to p. 59.—Ed.

- Japonites cf. Dieneri* Mart.
Acrochordiceras cf. Carolinæ Mojs.
Sturia Sansovinii Mojs.
Gymnites incultus Beyr.
 „ *cf. Humboldti* Mojs.
Anagymnites cf. acutus Hauer.
Ptychites Everesti Opp.¹
Proarcestes Balfouri Opp. (—*Escheri* Mojs).
Joannites cf. proavus Dien.
Monophyllites sphærophyllus Hau.

The close affinity of a considerable number of other species is scarcely less remarkable. The genus *Ptychites*, which plays a very important part both in the Upper Muschelkalk of the Alps and of the Himálayas, especially in number of individuals, is represented in both regions by many 'vicarious' types. The Himálayan species of *Pleuro-nautilus* are all nearly allied to others from the Reifingerkalk of the North-eastern Alps. Among the *Ceratites* three species, *Ceratites Thuillieri* Opp., *C. himalayanus* Blfd., *C. sp. ind. aff. Abichi* Mojs. exhibit close relations to congeneric forms of the *nodosi* group. The subgenera *Halilucites*, especially characteristic of the Bosnian Muschelkalk, and *Cuccoceras* are also represented in India, each by a single form nearly allied to European ones.

On the other hand there remains a sufficient number of peculiar faunistic elements, which impart to the Indian Triassic province the character of a zoo-geographical region of its own.

The most important of those elements peculiar to the Muschelkalk fauna of the Indian Trias are several subgenera of *Ceratites*, which predominate in the Upper Muschelkalk of the Himálayas. The section of *Ceratites circumplicati* (*Hollandites*), which is very poorly developed in the Mediterranean region, is the most remarkable group of Indian ceratites, being represented there by fifteen species. Those species of *Hollandites* show but very remote affinities with the Alpine representatives of this subgenus. Three species of *Ceratites* differ from all European types

¹ In the fauna of the Schiechlinghøhe near Hallstatt this species is represented by a form very closely allied or perhaps even identical with it, although its fragmentary state of preservation did not allow any definite judgment. *Vide* C. Diener, Die Cephalopodenfauna der Schiechlinghøhe, *Beiträge zur Palaont. und Geo., Oesterr. Ungarns. etc.*, XIII, p. 32.

so widely, that they have to be considered as prototypes of isolated subgenera. They are: *Peripleurocylus Smithianus* Dien., *Salterites Oberhummeri* Dien., *Haydenites Hatschekii* Dien. Two more new subgenera with ceratitic sutures, peculiar to the Indian Trias, are *Pseudodanubites* Hyatt. and *Bukowskiites* Dien.

In the genus *Beyrichites* we meet two isolated forms—*B. Gangadhara* Dien. and *B. Rudra* Dien. The same remark applies to the group of *Ptychites Malletianus* Stol. and *Ptychites Gerardi* Blfd., both representing types, which differ completely from the *Ptychites* of the Mediterranean region. Nor does *Buddhaites Rama* Dien. bear any closer relation to any of the Alpine species of *Gymnites*, *Pinacoceras* or *Carnites* although it unites characters of those three genera.

The most aberrant type in this fauna is perhaps *Smithoceras Durandii* Dien., the primitive ancestor of Upper Triassic *Juvavitinae*.

The *Lamellibranchiata* of the Himalayan Upper Muschelkalk are known to us very superficially only, but some species, as *Posidonomya cf. bosniaca* Bittn., are probably nearly allied to Alpine forms. A similar remark applies to the *Gastropoda*, which have been studied by Blaschke. Species of *Pleurotomaria* and *Worthenia* largely predominate, whereas species of *Naticopsidae*, *Neritidae* and all types with Palæozoic affinities, such as *Bellerophon*, *Capulus*, *Euomphalus*, are entirely absent.

In the zone of *Spiriferina Stracheyi* the affinities of the Indian and Alpine faunæ are much more remote. The species of *Brachiopoda* are all isolated types, which differ considerably from all Alpine congeneric forms, as has been stated by Bittner. Among the cephalopods *Stacheites* and *Dalmatites* are in Europe hitherto known only from the Campil beds of the Lower Trias. Four species of *Monophyllites*, which belong to the sections of *M. sphærophyllus* and *M. Suessii* (*Mojsvarites*), are distinguished from the congeneric forms of the Alpine Upper Muschelkalk by their simpler sutures, but one of them, *Monophyllites* (*Mojsvarites*) *Confucii* Dien., is so closely allied to *M. Suessii*, that Frech proposes to unite it with that species as a variety.¹ A second species, *Monophyllites Hara* Dien., has been discovered among Nopcsa's collections from

¹ F. Frech, Neue Cephalopoden aus dem südlichen Bakony, *Palæontologischer Anhang zu Resultate der Wissenschaftl. Erforschg. des Balatonsees*, Bd. I, Erster Teil., p. 17.

the Lower Trias of Keira in Albania by G. v. Arthaber.¹ Two species of *Orthoceras*—*O. cf. campanile* Mojs. and *O. cf. multilabiatum* Hauer—are probably identical with Alpine forms. A very interesting type is *Gymnites depauperatus* Dien., the most primitive species of that genus, any trace of ramification being absent in its sutural line, which is provided with saddles entirely dolichophyllic.

The most characteristic group of ammonites in the zone of *Spiriferina Stracheyi* is the Indian section of *Keyserlingites* (*Durgaites*) which, notwithstanding a remarkable convergence in external features, is not identical with the Siberian types of *Keyserlingites* (*Ceratites subrobusti*), their mode of development showing considerable differences. Since the Indian types of *Keyserlingites* cannot be allied phylogenetically to the Siberian ones, they must be considered as a faunistic element peculiar to the Himálayan Muschelkalk.

In America the fauna of the Muschelkalk in the West Humboldt range of Nevada, as studied by J. P. Smith,² shows such a distinctly Mediterranean character, "that a palæontologist from Austria might be set down in the Humboldt desert and he could hardly tell from the character of the fauna, whether he was collecting in Bosnia or in Nevada."

Although the predominance of Alpine elements shows that the relationship is much closer with the Mediterranean than with the Himálayan Muschelkalk fauna, there is sufficient evidence for a direct connection of the American Triassic province with the Indian regions during this epoch.

The subgenus *Hollandites*, which is of Indian origin, is represented in Nevada by two species nearly allied with Himálayan ones, *H. aff. Voiti* Opp. and *H. aff. Hidimba* Dien. The subgenus *Gymnotoceras* Hyatt (group of *Ceratites geminati*), which occurs abundantly in Nevada, is also represented in the Olenek beds of Siberia and in the Indian Muschelkalk, but not in the Alpine region. It seems therefore probable that at the Muschelkalk epoch the American Triassic province was connected on one side with the Mediterranean and on the other side

¹ Ueber die Entdeckung der Untertrias in Albanien, etc. *Mitteil. Geol. Ges. Wien.*, I, p. 286, Taf. XII, fig. 4.

² J. P. Smith, The stratigraphy of the Western American Trias, *Ad. v. Kænens Festschrift*, Schweizerbart, Stuttgart, 1907, p. 401.

with the Indian region, that the Central Mediterranean sea or "Tethys" formed an uninterrupted belt around the globe to the North of the Tropic of Cancer.

The faunistic affinities both with the boreal region of Siberia and with the Japanese province are more remote. The relationship of the American and Japanese faunæ has been exaggerated by E. v. Mojsisovics.¹ As has been demonstrated by J. P. Smith, there is almost no kinship whatever between the rich fauna of the Muschelkalk of Nevada and the poor faunæ from the Middle Trias of Japan. But the Indian fauna of this epoch is almost equally unlike that of Japan. *Ceratites* (*Danubites*) *Kansa* Dien. is perhaps the only species which has a remarkable resemblance with a Japanese form, viz., *Ceratites* (*Danubites*) *Naumanni* Mojs. The Indian species of *Japonites* are less closely allied to *J. planiplicatus* Mojs. from Okatsuhama than to the European types of this genus recently discovered in the Trias of Montenegro. It is therefore not likely that the connection between the American and Indian Triassic provinces was established by way of Japan during the Muschelkalk epoch. Their faunæ are related to each other more closely than either of them is to the fauna of Japan.

In the Siberian region deposits of Muschelkalk age are known to us from two localities only, from the Magyl rocks on the lower Yana, and from the Russian Island near Vladivostok (Ussuri district).

In the small fauna of the Magyl rocks discovered by Baron E. v. Toll, there is one species, *Beyrichites affinis* Mojs., which occurs also in the upper Muschelkalk of the Shalshal cliff. An affinity with the faunula from the Russian Island is indicated by the presence of a species of *Ptychites rugiferi*. There is also a close relationship between the Indian representatives of this group and the congeneric forms from Spitzbergen, but it is not closer than with the Mediterranean types.

Otherwise a comparison between the faunæ of the Himálayan Muschelkalk and of the Olenek beds of North-eastern Siberia offers but little support on behalf of a near kinship between the Indian and boreal regions. In this respect only the presence of *Gymnotoceras* (group of *Ceratites geminati*) in both regions might be mentioned, and the strange group of *Ceratites* (*Philippites*) *Jolinkanus* Dien. in Byans,

¹ E. v. Mojsisovics: Ueber einige Japanische Triasfossilien. *Beiträge zur Palæont. Oesterr. Ungarns, etc.*, VII, 1888, p. 163.

which in its external sculpture recalls the Arctic section of *Dinarites spiniplicati* (*Olenekites*), whereas in its sutures it agrees with *Keyserlingites Middendorffi* Keys. The affinity of the Arctic group of *Ceratites polaris* to the Indian subgenus *Hollandites* is extremely doubtful.

During the *ladinic* stage a close kinship still persists between the marine faunæ of the Himálayan and Mediterranean provinces. The *Daonella* shales of Spiti, which must be taken as prototype of this stage in India, have a considerable number of species in common with the Wengen beds of Tyrol. Those species are :—

- Protrachyceras Archelaus* Lbe.
- „ *longobardicum* Mojs.
- „ *ladinum* Mojs.
- „ *cf. regoledanum* Mojs.
- Anolcites cf. Laczkoi* Dien.
- Hungarites Pradoi* D'Arch.
- Joannites cf. Tridentinus* Mojs.
- Daonella Lommeli* Wissm.

Out of thirty species of the fauna of the *Daonella* shales only four belong to faunistic elements which are peculiar to the Indian zoo-geographical region. One of them is *Ptychites Gerardi* Blfd., which together with *Joannites cf. proavus* Dien. ranges from the Upper Muschelkalk into the *ladinic* stage. The second, *Thanamites bicuspidatus* Dien., belongs to a genus which recalls some Palæozoic ammonites in its very simple sutures, among which the narrow and bifid lateral lobe is especially conspicuous. It is a dwarf genus, which probably originated from some more specialised type by regressive evolution. Two more species are representatives of the genus *Rimkinites*, which is not known hitherto to occur in any extra-Indian territory.

This proportion of Mediterranean and exclusively Indian elements in the *ladinic* fauna of Spiti is not altered, if the fauna of the passage beds connecting the *Ptychites* limestone of the Upper Muschelkalk and the *Daonella* shales is included. Leaving aside such species as do not exhibit any affinity with Mediterranean forms, the relationship to Wengen species prevails so remarkably, that the fauna of the passage beds must also be considered as an equivalent of the zone of *Protrachyceras Archelaus* (*longobardic* substage).

Neither in the fauna of the Himálayan Muschelkalk nor of the *Daonella* shales and the passage beds connecting both divisions have any representatives of the Buchenstein beds of the Eastern Alps been noticed.

In the Mediterranean region the zones of *Protrachyceras Curionii* and *Dinarites avisianus* (Marmolatakalk) are intercalated between the zones of *Ceratites trinodosus* (Upper Muschelkalk) and of *Protrachyceras Archelaus* (Wengen beds), but no types of those two zones have been discovered in the Himálayan Trias. Two species only—*Hungarites sp. ind. aff. Mojsisovicsi* Boeckh and *Protrachyceras Cautleyi* Dien.,—from the passage beds in Spiti, show a distant affinity to the Buchenstein fauna. As there is certainly no stratigraphical break nor hiatus in the succession of Triassic beds in Spiti, equivalents of the Buchenstein beds of Tyrol must be included either in the Upper Muschelkalk or in the passage beds connecting it with the *Daonella* shales. The absence of any distinct Buchenstein types we may reasonably explain by the suggestion, that no independent fauna corresponding to that of the zone of *Protrachyceras Curionii* lived in the Indian Triassic province at the commencement of the ladinic epoch, which in the Himálayas was characterised by a survival of species from the zone of *Ceratites Thuillieri* and *Ptychites rugifer* into this stage.

This explanation has been adopted by J. P. Smith for the mingling of anisic and ladinic faunæ in the horizon of *Daonella dubia* in the West Humboldt range of Nevada, where otherwise typical equivalents of the ladinic stage are missing altogether.

As has been stated in the preceding chapter, the *Daonella* limestone, following conformably above the *Daonella* shales, must—partly at least—be included in the ladinic stage.

Monophyllites cf. Wengensis Klipst. and *Daonella Lommeli* Wissm. point to the Wengen beds, whereas *Joannites cf. Klipsteini* Mojs. and *Daonella aff. cassianæ* Mojs. are more nearly allied to species from the beds of St. Cassian (lower carnic stage). The genera *Traumatocrinus*, *Phloioceras*, *Styrites* have not as yet been found in Triassic beds older than the carnic stage. As fossils occur throughout the entire thickness of the *Daonella* limestone, this assemblage might be explained by their having been mixed in collecting from different horizons. In favour of such an explanation the fact might be urged, that according to A. v.

Krafft's notes, *Daonella Lommeli*, the most characteristic type of the ladinic stage in Europe, does not occur in the upper third of the Daonella limestone.

Thus there appears to be a gradual passage from the ladinic into the carnic stage in the Daonella limestone of Spiti.

III. THE UPPER TRIAS.

(Carnic, Noric and Rhætic stages.)

a. General notes on the classification of the Upper Trias in Spiti and Painkhanda.

The division of the Upper Trias in the Austrian Alps has been based on faunistic, not on lithological characters. Nevertheless the two main stages are marked by lithological differences in the majority of sections, the carnic stage being comparatively poor in limestones, as compared with the ladinic and noric stages. This is, at least, the case throughout the entire range of the Noerdliche Kalkalpen.

In the Himálayas there is no doubt about the possibility of distinguishing two different rock groups in the Upper Trias, a lower one, poor in limestones, and an upper one consisting of pure limestones and dolomites. In the Himálayas, a natural classification, based on lithological characters, suggests itself at once to the geologist who is surprised by the sharp contrast between the dark-coloured slopes, consisting of alternating shales, marls, limestones and quartzites, which form the pedestal of the high ranges, and the light grey dolomites and limestones of the cliffs and jagged peaks towering above them.

To the lower group, which is comparatively poor in limestones, belong the beds between the Daonella limestone and the white quartzite series in Spiti and the zone of *Halobia comata* in Painkhanda. Of the upper division the Himálayan Dachsteinkalk is the prototype in both districts.

It might, perhaps, be more correct to say that the lower division is not exactly poor in limestones, but that calcareous sediments are always intermixed with marly, clayey and arenaceous ones to such an extent that the latter rocks predominate considerably. Pure limestones—nearly always of a dark colour—are noticed only as intercalations between

shales, sandstones and quartzites. Such limestone horizons are in Spiti : the limestone banks within the grey beds, the black, splintery limestone intercalated between the shaly limestones and shales of the covering series, the very thick mass (about 300 feet and even more) of the limestone with *Spiriferina Griesbachi*, the so-called "Coral limestone" and the limestone between the two quartzite series. In Painkhanda we may mention the limestones containing the faunæ of *Proclydonautilus Griesbachi* and *Halorites procyon*, the brachiopod-bearing beds with *Spiriferina Griesbachi*, and the liver-coloured limestones with *Sagerites sp. ind.*, which are intercalated between arenaceous shales, sandstones and quartzites.

It is consequently evident that in the Upper Trias of the Central Himālayas of Painkhanda and Spiti two natural rock groups can be distinguished lithologically, a lower one composed of clayey, arenaceous and calcareous sediments and an upper one of pure limestones and dolomites. But those two natural rock groups do not correspond to stratigraphical stages. The boundary between the carnic and noric stages is not at all marked lithologically, but runs through a uniform series of sediments equally developed, which are comparatively poor in pure limestones. The same physical conditions prevailed during the carnic and lower noric epochs. Nor does the remarkable change in sedimentation, which corresponds to the limits between the Upper Triassic quartzites and the dolomites of the Dachsteinkalk coincide with the boundary of the two stratigraphical stages.

The lower group of the Himālayan Upper Trias comprises both the carnic and noric stages of the Alpine Trias, whereas the uniform mass of grey limestones and dolomites following above, includes not only equivalents of the noric and rhætic Dachsteinkalk of the Eastern Alps, but even of the Lias and Oolite.

b. The Carnic stage in Spiti and Painkhanda.

It has been explained that in Spiti, according to A. v. Krafft's descriptions, the ladinic *Daonella* shales are overlaid by a homogeneous mass of dark splintery limestone, measuring about 280 feet in thickness. In its lower division—A. v. Krafft's "*Daonella limestone*"—it contains a fauna with ladinic and carnic affinities. As far as *Daonella Lommeli* Wissm. occurs in this rock-group, its ladinic age has been ascertained.

The topmost portion of the *Daonella* limestone is probably of carnic age.

On the top of the *Daonella* limestone—145 feet above the upper limit of the *Daonella* shales in the section of Lilang—a black limestone alternating with shales, 25 feet in thickness, has been observed by A. v. Krafft dividing the otherwise homogeneous mass of limestone. This is the bed of *Joannites thanamensis* Dien. The upper division of the mass of dark splintery limestone, following above the bed of *Joannites thanamensis*, has yielded *Halobia* cf. *comata* Bittn., a species typical of the julic substage in the Himálayas.¹

Above the “*Halobia* limestone” grey, earthy shales follow, in which grey, shaly limestones of various thickness are intercalated. About 260 feet above the base of this series of “grey beds” a thin-bedded, shaly limestone of 20 feet in thickness has been noticed.

Fossils have been discovered in two horizons. Almost immediately above the *Halobia* limestone the shales contain a band of black concretions, which enclose numerous ammonites. The following species have been determined by Diener²:—

Trachyceras sp. ind. aff. *Ariæ* Mojs.

„ sp. ind. (group of *acanthica*).

Carnites floridus Wulf.

„ cf. *nodiger* Dien.

Joannites cymbiformis Wulf.

Monophyllites sp. ind. aff. *Simonyi* Hauer.

The second fossiliferous horizon occurs about 300 feet above the base and about 40 feet above the thin-bedded limestone referred to above. Fossils are known from two localities, N. N. W. of Lilang and N. W. of Muth. There is only one single species of ammonite among them, and this is so poorly preserved that an exact determination is impossible. It has been referred to the genus *Paratropites* Mojs. provisionally by Diener (*l. c.*, p. 149). But the fauna of both localities is rich in brachiopods and bivalves, which belong to the following species:—

Rhynchonella laucana Bittn.

„ *laucana* var. *lilangensis* Bittn.

¹ H. Hayden, *Geology of Spiti*, l. c., p. 76.

² C. Diener, *Ladinic, carnic and noric faunæ of Spiti, Himál. Foss., Pal. Ind.*, ser. XV, Vol. V, Pt. 3, p. 148.

- Rhynchonella cf. semiplecta* Muenst.
 „ *Freshfieldi* Dien.
 „ *himaica* Dien.
 „ *cf. bajuvarica* Bittn.
 „ (*Austriella*) *sp. ind. aff. nux* Suess.
Spiriferina gregaria Suess.
 „ *aff. shalshalensis* Bittn.
 „ *orophila* Dien.
 „ *deodarae* Dien.
Mentzelia Mentzelii Dunk.
Aspidothyris Krafftii Dien.
Dielasma Julicum Dittn.
 „ *Haydeni* Dien.
Crurātula (?) *indica* Dien.
Lilangina nobilis Dien.
Pomarangina Haydeni Dien.
Lima sp. ind. aff. alternans Bittn.

The series of shaly limestones, grey earthy shales and calcareous shales, with bands of dark, splintery limestones intercalated occasionally, continues above this second fossiliferous horizon, until a bed of nodular limestone, 15 feet in thickness, is reached, 600 feet above the brachiopod bed or 900 feet above the basal horizon of *Joannites cymbiformis*.

This third fossiliferous horizon of carnic age is the "Tropites limestone" of Lilang and Tikha. It is rich in *Cephalopoda*, most of which, however, are badly preserved. The following forms permit of a specific determination :—

- Clydonautilus acutilobatus* Dien.
Germanonautilus cf. Breunneri Hauer.
Styrionautilus cf. Sauperi Hauer.
Pleuronautilus sp. ind. aff. Wulfeni Mojs.
Tropites cf. subbullatus Hau.
 „ *discobullatus* Mojs.
 „ *cf. torquillus* Mojs.
 „ *sp. ind. aff. Paracelsi* Mojs.
Paratropites tikhensis Dien.
Trachysagenites cf. Herbichi Mojs.

- Trachysagenites galeatus* Dien.
Discotropites sp. ind. aff. *Plinii* Mojs.
Anatomites cf. *Bacchus* Mojs.
Jovites spectabilis Dien.
 „ cf. *siculus* Gemm.
Sandlingites nov. sp. aff. *Reyeri* Mojs.
 „ nov. sp. aff. *Castellii* Mojs.
Clionites heracitiformis Dien.
Proarcestes cf. *Gaytani* Klipst.¹

Grey shaly limestones and calcareous shales continue with the same lithological characters for the next 200 feet. Seventy feet above the nodular limestone a specimen of *Jovites spectabilis* Dien. was discovered by A. v. Krafft, who consequently includes the entire series following above the concretionary limestone with *Cephalopoda* in his “Tropites beds.”

The next overlying bed is a dolomitic limestone, whose thickness amounts to 300 feet. It has yielded few and badly preserved fossils, with carnic affinities, among them :—

- Dielasma jolicum* Bittn.
Terebratula sp. ind. aff. *piriformis* Suess.
Spiriferina sp. ind. aff. *shalshalensis* Bittn.
Lima cf. *austriaca* Bittn.
Halobia aff. *superba* Mojs.
Daonella aff. *styriaca* Mojs.

With this complex of dolomitic limestones the carnic stage comes to a close. Its entire thickness in the section of Lilang amounts to at least 1,600 feet.

In Painkhanda the development of the carnic stage is more uniform.

In the Bambanag and Shalshal cliffs the lowest cephalopod horizon of this stage was discovered by Diener in the grey “*Traumatocrinus* limestone,” which, according to A. v. Krafft, is separated from the *Ptychites* beds of the Upper Muschelkalk by an insignificant

To this list *Griesbachites Medleyanus* Stol. must probably be added. Stoliczka's type-specimen, which was found loose in the Pin valley near Kuling, is referred to the Tropites beds by A. v. Krafft. A similar remark applies to *Paracladiscites indicus* Mojs. from the same locality.

development of the ladinic stage. It has, however, been demonstrated in the preceding chapter that the ladinic age of those passage beds has not yet been established with full certainty.

The scanty materials collected by the expedition in 1892 were described by E. v. Mojsisovics and A. Bittner. The rich fauna, which was brought together by A. v. Krafft in 1900, has been examined by Diener.¹ It consists of the following species, which show at once and indubitably the juric age of the Traumatocrinus limestone:—

Proctydonautilus cf. buddhaicus Dien.

Grypoceras rimkinense Dien.

„ *sp. ind. aff. rimkinensi* Dien.

„ *Stirlingii* Dien

Joannites cymbiformis Wulf.

„ *Klipsteini* Mojs.

„ *Kossmati* Dien.

„ *Mojsvari* Dien.

Proarcestes cf. ausseanus Hau.

„ *sp. ind.*

Lobites (Coroceras) cf. delphinocephalus Hau.

„ „ *valdecucullatus* Dien.

Monophyllites cf. Simonyi Hau.

„ (*Mojsvarites*) *Agenor* Muenst.

Juvavites (Anatomites) sp. ind.

Isculites cf. Heimi Mojs.

Celtites contractifrons Dien.

Carnites cf. floridus Wulf.

Placites cf. polydactylus var. Oldhami Mojs.

Rimkinites nitiensis Mojs.

„ *Edmondii* Dien.

Arpadites rimkinensis Mojs.

„ (*Dittmarites*) *cf. circumscissus* Mojs.

„ „ *sp. ind. aff. Ladon* Dittm.

Clionites nov. sp. ind. aff. Doræ Mojs.

Trachyceras austriacum Mojs.

„ *austriacum var. tibetica* Mojs.

Protrachyceras sp. ind. aff. Arion Mojs.

¹ C. Diener, The fauna of the Traumatocrinus limestone, etc., Himál. Foss., *Pal. Ind.*, ser. XV, Vol. VI, Pt. 2.

Protrachyceras sp. ind. (group of *furcosa*).

Sirenites Cookei Dien.

Girthiceras pernodosum Dien.

Daonella indica Bittn.

„ sp. ind. aff. *obliqua* Mojs.

Avicula sp. ind. aff. *seisiana* Broili.

Pecten nov. sp. ind. aff. *subalternans* Bittn.

Heminajas sp. ind. (cf. *Woehrmanni* Waag).

Spirigera hunica Bittn.

Retzia sp. ind. aff. *ladina* Bittn.

Aulacothyris nilangensis Bittn.

Rhynchonella rimkinensis Bittn.

„ (*Austriella*) sp. ind. aff. *Middlemissii*.

„ (*Norella*) *Kingi* var. *tibetica* Bittn.

Traumatocrinus sp. ind.

Above the *Traumatocrinus* limestone, whose thickness barely exceeds ten feet, follows a thin limestone bed, which has yielded the following brachiopods and bivalves:—

Norella Kingi Bittn.

„ *tibetica* Bittn.

Spirigera hunica Bittn.

Aulacothyris nilangensis Bittn.

Daonella indica Bittn.

This is the highest stratigraphical horizon into which *Daonella indica* Bittn. reaches.

Before continuing this account of the carnic deposits of Painkhanda, it is worth mentioning that a fauna corresponding to that from the bed following immediately above the *Traumatocrinus* limestone was discovered by C. L. Griesbach on the summit of a pass leading from Hop gíd'h to Dogkwa aur, N.E. of Tsang chok La in Hundes. From this locality the following fossils were determined by Bittner¹:—

Aulacothyris nilangensis Bittn.

Spirigera hunica Bittn.

Norella tibetica Bittn.

Discina sp. ind.

Daonella indica Bittn.

¹ A. Bittner, Himál. Foss., Vol. III, Pt. 2, pp. 30, 31, 32, 33, 39.

These fossils point to a carnic age of the beds from which they were derived. The actual section in the Trias of the Hop gádh differs, according to Griesbach (*Memoirs, Geol. Surv. India*, Vol. XXIII, p. 205), in no way from those of the Niti area.

Above the limestone bed with *Daonella indica* there follows in the sections of the Shalshal and Bambanag cliffs a mighty series of dark, calcareous shales and shaly limestones, amounting to between 650 and 800 feet in thickness. Cephalopods and bivalves occur throughout this series, but especially in the lower beds. Most of the fossils were collected near Lauka encamping ground on the way from the Uttardhura to the Girthi valley by Diener. The complex was originally designated "Daonella beds" by Griesbach, but the name "Beds with *Halobia comata*" appears to be more appropriate, since *Daonella* is replaced in those beds by *Halobia* of the *rugosa*-group.

The following species of *Brachiopoda* and *Lamellibranchiata* were described by A. Bittner (l. c., p. 72):—

Spiriferina shalshalensis Bittn.

Retzia Schwageri var. *asiatica* Bittn.

Rhynchonella laucana Bittn.

Halobia comata Bittn.

„ *fascigera* Bittn.

Avicula girthiana Bittn.

Cassianella pl. sp. ind.

The following species of *Cephalopoda* were quoted by E. v. Mojsisovics (l. c., p. 129):—

Pleuromutilus tibeticus Mojs.

Jovites sp. ind. ex. aff. *daci* Mojs.

Discotropites sp. ind. aff. *Plinii* Mojs.

Juvavites cf. *tonkinensis* Dien.¹

Anatomites bambanagensis Mojs.

„ *Eugenii* Mojs.

„ *Caroli* Mojs.

Griesbachites Hanni Mojs.

Hypocladiscites subaratus Mojs.

Placites sp. ind. ex. aff. *peraucto* Mojs.

„ *polydactylus* var. *Oldhami* Mojs.

¹ C. Diener, Note sur deux espèces d' Ammonites Triasiques du Tonkin, *Bull. Soc. Geol. de France*, 3, ser. XXIV, p. 882.

Mojavarites eugyrus Mojs.
Discophyllites Ebneri Mojs.

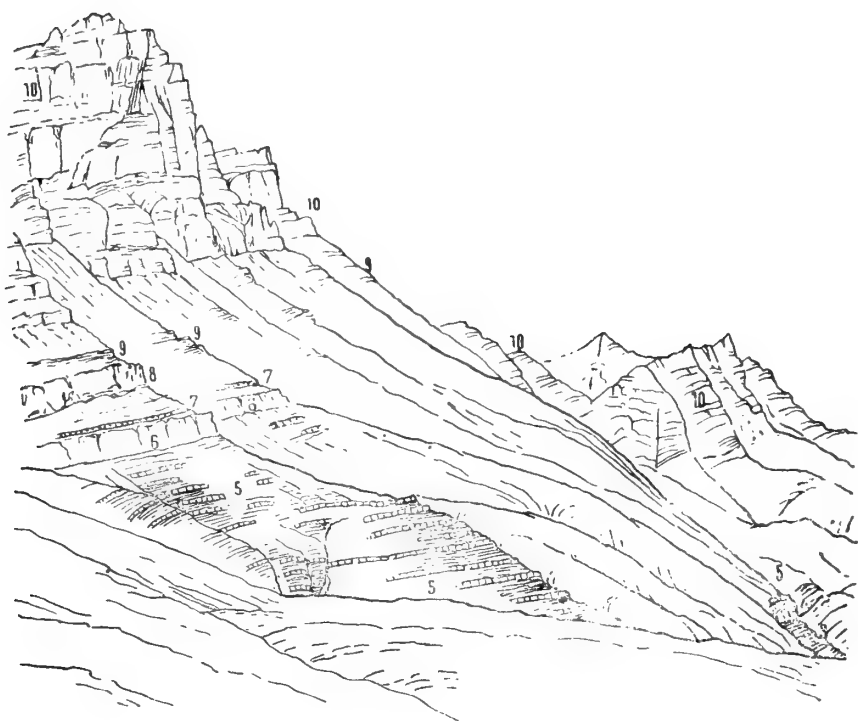


FIG. 5. Slopes of the Shalshal cliff above Rimkin Paar E. G.

10. Megalodon limestone.
9. Quartzite series.
8. Dolomitic limestone with *Spiriferina Griesbachi*.
7. Halorites limestone.
6. Limestone with *Proctydonautilus Griesbachi*.
5. Shaly limestones and shales with *Halobia comata*.
4. Muschelkalk.
3. Lower Trias and *Productus* shales.
2. White Quartzite.
1. Silurian.

To these species must be added a considerable number of forms, belonging to the genera *Juvavites*, *Sagenites*, *Styrites*, *Tibetites*,

Paracladiscites, *Megaphyllites*, *Proarcestes*, *Clydonautilus*, which could not be determined specifically.

The beds with *Halobia comata* are overlaid by the nodular limestone with *Proclydonautilus Griesbachi* Mojs., which contains a fauna of indubitably noric age.

The entire thickness of the carnic stage in Painkhanda barely exceeds 800 feet, that is to say only half of the thickness of this stage in Spiti. Nor can an equal number of stratigraphical horizons be distinguished in the carnic series of the two districts.

c. The Noric and Rhætic stages in Spiti and Painkhanda.

In the section of Lilang a series of brown-weathering limestones alternating with shales and sandstones, follows conformably above the dolomitic limestone with *Lima cf. austriaca* Bittn. and *Dielasma julicum* Bittn. Its thickness amounts to 500 feet.

In the upper division of this series *Cephalopoda* are common, especially ammonites of the genus *Juvavites* Mojs. The name "Juvavites beds" proposed by A. v. Krafft is indeed very appropriate for this rock group.

Juvavites angulatus Dien. is the chief leading fossil. It is a representative of the section of *continui*, but does not show a close affinity to any European or American species of this genus. The fauna of the Juvavites beds consists of the following forms:—

Atractites sp. ind. cf. *alveolaris* Quenst.

Paranautilus arcestiformis Dien.

Pleuromautilus sp. ind. aff. *Kossmati* Dien.

„ cf. *ibeticus* Mojs.

Indonautilus cf. *Krafftii* Mojs.

*Dittmarites lillii*formis Dien.

„ cf. *traillii*formis Dien.

Clionites sp. ind. cf. *Hughesii* Mojs.

Metacarnites Footei Dien.

„ *Hendersoni* Dien.

Pinacoceras sp. ind. ex. aff. *parma* Mojs.

Tibetites cf. *Ryalli* Mojs.

*Anatibetites Kelvinii*formis Dien.

- Paratibetites Tornquisti* Mojs.
 „ *sp. ind. aff. Wheeleri* Dien.
Juvavites angulatus Dien.
 „ *sp. ind. aff. Ehrlichii* Hau.
Anatomites sp. ind. aff. Melchioris Mojs.
 „ *sp. ind. aff. Caroli* Mojs.
 „ *sp. ind. aff. Alphonsi* Mojs.
Dielasma aff. julico Bittn.
Halobia sp. ind. aff. fascigeræ Bittn.
Pecten (Amusium) margarito costatus Dien.
Pecten sp. ind. aff. monilifero Muenst.
Lima cf. serraticosta Bittn.
Homomya sp. ind. aff. larianæ Stopp.
Mytilus sp. ind. aff. rugoso Roem.
Mysidioptera sp. ind.

The Juvavites shales become calcareous in the upper portions and pass into concretionary limestones, which resemble gradually the concretionary limestone of the Muschelkalk in their lithological characters. Near the top of the series some beds of calcareous sandstones with plant remains have been noticed by A. v. Krafft.

The calcareous sandstones with plant remains form the base of the next rock-group, A. v. Krafft's "Coral limestone." It is a mass of grey limestone, about 100 feet in thickness. In the section of Lilang it is a true organogenic limestone in which remains of crinoids and corals abound. But in the section of Kágá corals occur rather rarely, and none at all have been found W. of Chabrang. Otherwise the coral limestone is very poor in well-preserved fossils. Only two species of brachiopods are known from it, namely :—

- Spiriferina Griesbachi* Bittn.
Rhynchonella bambanagensis Bittn.

The coral limestone is overlain by flaggy sandstones alternating with black, splintery shaly limestones and sandy shales. The thickness of this series, which lithologically recalls the Juvavites beds, is about 30 feet.

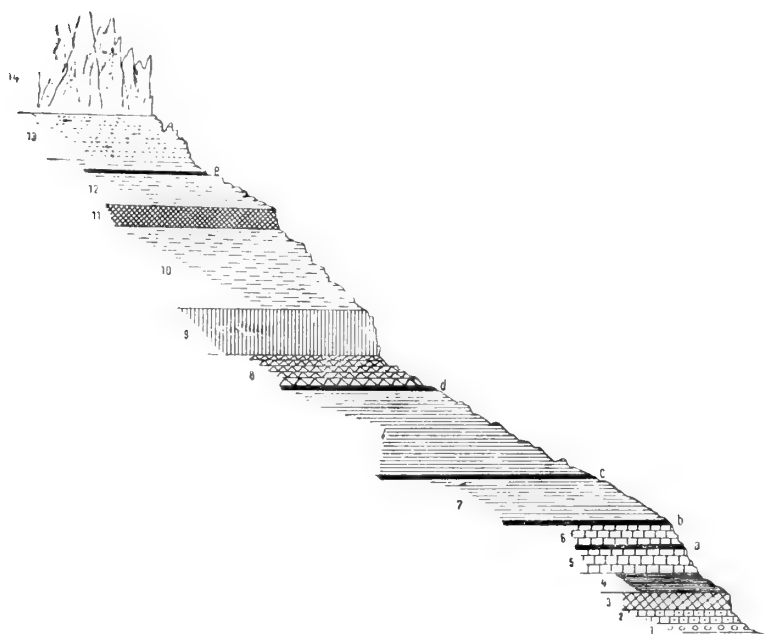


FIG. 6.—Generalized section near *Lilang* (from A. v. Kraft's diary).

14. Megalodon limestone.
13. Quartzite series.
12. Monotis beds.
11. Coral limestone.
10. Juvavites shales.
9. Dolomitic limestone with *Lima cf. austriaca*.
8. Tropites shales.
7. Grey beds.
6. Halobia limestone.
5. Daonella limestone.
4. Daonella shales.
3. Muschelkalk.
2. Lower Trias.
1. Productus shales.

- a. Horizon of *Joannites thanamensis*.
- b. „ „ *Joannites cymbiformis*.
- c. Brachiopod layer of the Grey Beds.
- d. Main layer of *Tropites subbullatus*.
- e. „ „ „ *Monotis salinaria*.

A. v. Krafft describes a sequence, which he observed near Lilang. as follows :—

6. Yellow-weathering, shaly limestones and shales with *Spiriferina Griesbachi* Bittn.

5. Brown sandstones, alternating with grey sandy shales, rich in *Lamellibranchiata* (chiefly *Monotis salinaria* Schloth).

4. Black, splintery limestone.

3. Brown, flaggy sandstones, with partings of sandy shales.

2. Grey, hard limestone, with calcite veins.

1. Brown, flaggy sandstones.

It is chiefly the group No. 5, which has yielded a considerable number of fossils, among them *Monotis salinaria* Schloth.

Together with this characteristic bivalve, the following species of *Brachiopoda*, *Lamellibranchiata*, and *Cephalopoda* were collected in the “*Monotis* beds” by A. v. Krafft :—

Spiriferina Griesbachi Bittn.

Spirigera Dieneri Bittn.

Aulacothyris joharensis Bittn.

Rhynchonella bambanagensis Bittn.

Anodontophora Griesbachi Bittn.

Pecten margariticostatus Dien.

„ *sp. ind. aff. Massolongi* Stepp.

„ *sp. ind. aff. monilifero* Muenst.

Lima cf. serraticosta Bittn.

Pleuromya himaica Dien.

Trachypleuraspides nov. sp. ind. aff. Griffithi Dien.

Immediately above the *Monotis* beds a series of white and brown quartzites occurs, which has a thickness of about 300 feet. This characteristic “*Quartzite series*” forms a most conspicuous horizon throughout Spiti and in the scenery is often distinguishable at great distances by the whiteness of the quartzite bands.

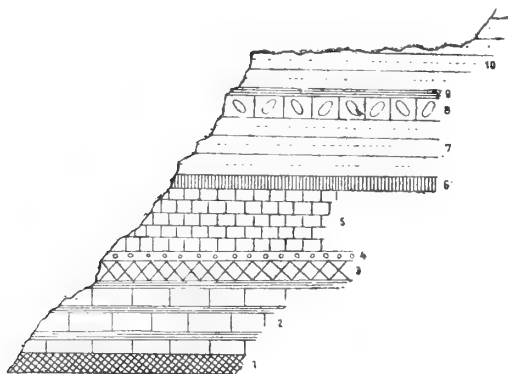


FIG. 7.—Section between Mani and Pin valley (from A. v. Krafft's diary).

10. White quartzite.
9. Shales.
8. Limestone with big markings.
7. Quartzite.
6. Dolomitic band with bivalves.
5. Sandy dolomites with *Rhynchonella maniensis*.
4. Brown quartzite.
3. Megalodon limestone.
2. Limestones with shaly partings, containing *Spiriferina Griesbachi*.
1. Monotis shales.

As a rule three different layers of quartzite can be distinguished, separated from each other in the lower part of the series by limestones, but towards the top by black, shaly beds. The system varies somewhat, but it will suffice to mention the sequence, as observed near Lilang by A. v. Krafft, which is as follows (in descending order) :—

6. Great thickness of black and grey dolomitic limestones.
5. Thick brown quartzite.
4. Black, sandy shales, with *Aulacothyris joharensis* Bittn., alternating with thin, brown quartzite layers : 100 feet.
3. Thin band of white quartzite.
2. Dark grey hard limestone with *Spiriferina Griesbachi* Bittn. and *Lima serraticosta* Bittn. : about 200 feet.
1. Brown quartzite : about 20 feet.

Faunistically the quartzite series is distinguished by the presence of *Spirigera maniensis* Krafft, which is restricted to this stratigraphical

horizon. Most of the species are common to this series and to the lower Monotis beds.

The fauna of the quartzite series consists of the following forms :—

Spiriferina Griesbachi Bittn.

Spirigera maniensis Krafft.

„ (?) *maniensiformis* Dien.

Aulacothyris joharensis Bittn.

Rhynchonella bambanagensis Bittn.

Pecten, *sp. ind. aff. monilifero* Muenst.

Lima cf. serraticosta Bittn.

„ *sp. ind. aff. cumaunicæ* Bittn.

The lower series of the Upper Trias, which is comparatively poor in pure limestones, is overlaid in all sections conformably and regularly by a great thickness of grey limestones and dolomites, which in their lithological characters recall most strongly the Alpine Dachsteinkalk. Part of this enormous limestone mass, which underlies the Jurassic Spiti shales, represents indeed the European Dachsteinkalk while another part belongs to geologically younger beds (Lias and Oolite).

This Upper Triassic group of well-bedded limestones and dolomites, which C. L. Griesbach included almost entirely in his “rhætic system,” is well defined towards its base by the quartzite series, but its upper boundary is quite uncertain. The entire thickness of the limestone mass is about 2,300 feet, of which at least 800 feet belong to the Upper Trias.

Lithologically this mass of limestones and dolomites is too uniform and faunistically it is too poor in fossils to be subdivided in any greater detail.

Near Hansi a band of limestone, about 20 feet thick, which occurs 50 feet above the quartzite series, contains immense numbers of *Megalodon ladakhensis* Bittn. and *Dicerocardium himalayense* Stol.¹ This is the horizon of Stoliczka’s “Para limestone,”² blocks of which are very common throughout the upper Para valley, according to Hayden.

¹ H. Hayden, *Geology of Spiti*, l.c., p. 84.

² F. Stoliczka, *Mem., Geol. Surv. of India*, Vol. V, p. 124.

Between 200 and 300 feet above the base of the system the following species were found by A. v. Krafft :—

- Spirigera Noetlingi* Bittn.
Spiriferina cf. *Haueri* Suess.
Lima cumaunica Bittn.
Pecten chabrangensis Dien.
 „ sp. ind. aff. *Landrano* Bittn.
Entolium cf. *subdemissum* Muenst.
Megalodon ladakhensis Bittn.

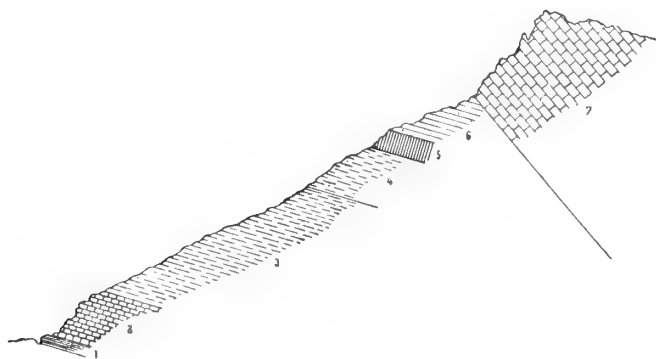


FIG. 8.—Section between Kibber and K_i (from A. v. Krafft's diary).

7. *Megalodon* limestone.
6. *Juvavites* shales.
5. Dolomites with *Lima* cf. *austriaca*.
4. *Tropites* shales.
3. Grey Beds.
2. *Daonella* and *Halobia* limestone.
1. *Daonella* shales.

It is evident from this faunula that, notwithstanding the scarcity of fossils, the beds including it are still equivalent to the Upper Trias.

About 400 feet above the base of the system a white, dolomitic band, 30 feet in thickness, was observed in several sections by A. v. Krafft, but has not yielded any fossils. Beds with rhætic types are entirely absent.

That the upper portion of the limestone mass is of Middle Jurassic age, may be inferred from the occurrence of *Stephanoceras cf. coronatum* Brug. in a limestone band, situated about 370 feet below the base of the Spiti shales near Giimal.

About 1,000 feet below the layer in which *Stephanoceras cf. coronatum* was found by A. v. Krafft, specimens of *Spiriferina cf. obtusa* Opp. have been collected between Giimal and Chabrang. This species may probably indicate a liassic age for the bed in which it occurs. We may therefore assume that approximately 500 feet of the limestone mass capped by the Spiti shales belongs to the Jurassic and 800 feet to the Triassic system. The middle portion of the limestone series must be of liassic age. To define the various horizons accurately within this homogeneous mass, is entirely impossible, owing to the scarcity of determinable fossils.

What has been said about the Upper Triassic limestone or Dachsteinkalk of Spiti, applies equally to Painkhanda and Johar, the boundary between the Triassic and Jurassic systems being not known exactly.

In the sections examined by Diener¹ the homogeneous mass of grey limestones and dolomites is capped by beds which are certainly younger than Triassic.

Two sections have been described by Diener. One of them, which follows the ravine cutting through the rim of the Shalshal cliff near Shalshal encamping ground, runs as follows :—

7. Lower Spiti shales, with *Belemnites Gerardi* Opp.
6. Sulcacutus beds, Kelloway : 6 feet.
5. Yellow-grey, earthy limestones and marls, with *Rhynchonella sp. ind.*: 4 feet.
4. Thin-bedded yellow-grey limestones with *Belemnites sp.*, *Ostraea sp.*, *Pecten sp.* : 20 feet.
3. *Lithodendron* limestone, with crinoid stems : 100 feet.
2. Thin-bedded limestones, with many bivalves of liassic affinities.
1. Well-bedded limestones, lithologically identical with the Upper Triassic limestones, following above the quartzite series.

¹ C. Diener, Ergebnisse, etc., l. c., pp. 583, 584.

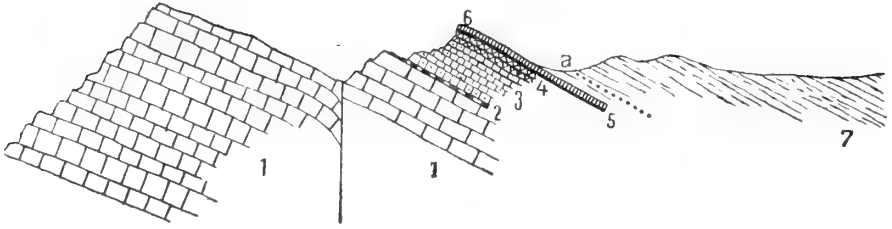


FIG. 9.—Section between the edge of the Shalshal cliff and the watershed along the route from Shalshal E. G. to Chota Hoti.

7. Spiti shales.
- 7a. Main layer of *Belemnites Gerardi*.
6. *Sulcacutus* beds.
5. Yellow-grey, earthy limestones and marls with *Rhynchonella* sp.
4. Yellow-grey, thin-bedded limestone with bivalves.
3. *Lithodendron* limestone.
2. Thin-bedded bivalve limestone.
1. Well-bedded limestone lithologically identical with the Upper Triassic *Megalodon* limestone.

The second section between Chidamu E. G. and Kiangur E. G. is distinguished from the preceding one only by the absence of the *Lithodendron* limestone No. 3. The fossils collected from the bivalve limestone No. 2 are of a rather indifferent habit, but rhætic types are certainly absent, as has been stated by Bittner, our late authority on Alpine Triassic lamellibranchs.

Thus the beds capping the limestone No. 1 are certainly younger than Triassic, but whether they should be included in the Lias or Oolite, could not be decided.

Below the bivalve limestone No. 2 there still remains a limestone mass of approximately 1,800 to 2,000 feet in thickness, the lower portion of which certainly belongs to the Upper Trias. But from what we know of Spiti, it is hardly possible that the entire mass is of Triassic age. In Griesbach's section of the Shalshal cliff,¹ *Belemnites* sp. is mentioned from bed 28, that is 189 feet below the base of the Spiti shales. This discovery cannot be overlooked, although the specimen has been apparently lost.

¹ C. L. Griesbach, *Mem., Geol. Surv. of India*, l. c., p. 139 (Geology of the Central Himalayas).

It is true that sections of *Megalodon* have been noticed occasionally even in the topmost beds of the limestone No. 1, but the mere occurrence of a specifically indeterminable *Megalodon* is, of course, no proof of a Triassic age, for in Southern Tyrol this genus ranges up from Triassic into liassic strata.

The development of the noric stage below the homogeneous mass of Upper Triassic limestones is nearly identical in Spiti and Painkhanda.

At the base of the Dachsteinkalk, if we are permitted to make use of this term, a series of white and brown quartzites, alternating with concretionary limestones and shales, can be observed in the sections of the Bambanag and Shalshal cliffs. Its thickness amounts to 250 feet.

Diener, it is true, has already mentioned beds of quartzitic sandstone as occurring at the base of the Dachsteinkalk, but A. v. Krafft was the first to recognise the stratigraphical importance of this horizon. The development of this quartzite series is very similar to that in Spiti. Moreover, the characteristic leading fossil, *Spirigera maniensis*, was also found by him in the Bambanag section, besides a few other forms, known from lower and higher beds, namely :—

Aulacothyris joharensis Bittn.

Spirigera cf. *Noettingi* Bittn.

„ *Dieneri* Bittn.

Pecten interruptus Bittn.

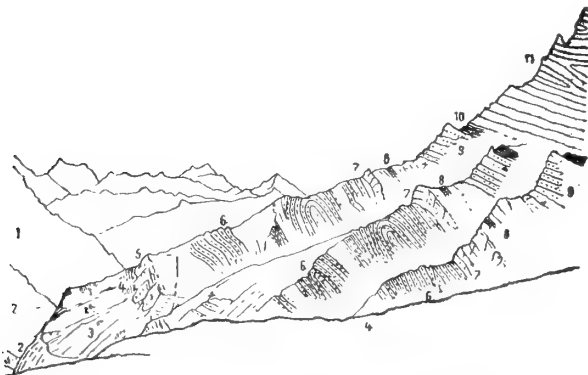


FIG. 10.—Section through the slopes of the Bambanag cliff.

11. *Megalodon* limestone.

10. Quartzite series.

9. Limestone with *Spiriferina Griesbach*.

8. Halorites beds.
7. Limestone with *Prochlydonautilus Griesbachii*.
6. Shales with *Halobia comata*.
5. Muschelkalk.
4. Lower Trias.
3. Productus shales.
2. White Quartzite.
1. Silurian.

The quartzite series is underlain by liver-coloured limestones recalling the beds of the Torer Sattel in the section of Raibl (Carinthia) in their lithological character. They have yielded only one fragmentary specimen of an ammonite, *Sagenites* sp. ind., from which the group was named "Sagenites beds." Seeing that this fragment of *Sagenites* is not determinable specifically, it is perhaps advisable to discard that name. As *Anodontophora Griesbachii* Bittn. (Griesbach's *Corbis* cf. *meltingi*) is particularly common in this horizon, it might be termed from this leading fossil "Beds with *Anodontophora Griesbachii*."

The thickness of this group has been estimated at 130 feet by Diener, and 160 feet by A. v. Krafft in the Bambanag section.

Below the liver-coloured limestone with *Anodontophora Griesbachii* there follows a mass of compact limestones, which are often dolomitic or micaceous and about 320 feet in thickness.

They are rich in brachiopods and bivalves, which were described by A. Bittner (l.c., p. 72). From their leading fossil they have been termed "Beds with *Spiriferina Griesbachii*." Their fauna consists of the following forms:—

- Spiriferina Griesbachii* Bittn.
- Retzia Schwageri* Bittn.
- Spirigera Dieneri* Bittn.
- Amphiclina* sp. ind.
- Rhynchonella bambanagensis* Bittn.
- „ *martoliana* Bittn.
- Aulacothyris joharensis* Bittn.
- Lima cumaunica* Bittn.
- Pecten biformatus* Bittn.
- „ *interruptus* Bittn.
- Anodontophora Griesbachii* Bittn.
- Cassianella pulchella* Bittn.

The brachiopod-bearing limestones with *Spiriferina Griesbachii* gradually pass at their base into black calcareous shales, with dark limestone bands intercalated between them. One of those limestone bands, situated about 180 feet below the lower limit of the beds with *Spiriferina Griesbachii*, contains the richest fauna of noric age, which has as yet been discovered in the Himálayas. This is Diener's "Halorites limestone" of the Bambanag section.

The fossiliferous horizon of the Halorites beds was traced by Diener, Griesbach and Middlemiss from Lauka encamping ground and the Jandi pass in Johar to the Shalshal cliff in Painkhanda, but nowhere was there found a section which, for abundance of *Cephalopoda* could be compared with that of the Bambanag cliff. The rich fauna collected by the expedition in 1892 was described by E. v. Mojsisovics.¹ Very extensive collections obtained by A. v. Krafft in 1900 were examined by C. Diener.²

The following *Cephalopoda* have been determined specifically by those two authors :—

- Halorites Sapphonis* Mojs.
- „ *procyon* Mojs.
- „ *Charaxi* Mojs.
- „ *Phaonis* Mojs.
- „ *Alcaci* Mojs.
- „ *Trotteri* Dien.
- „ *alternans* Dien.
- Anatomites* *sp. ind. ex. aff. scissi* Mojs.
- Parajuvavites Blanfordi* Mojs.
- „ *laukanus* Mojs.
- „ *Sternbergi* Mojs.
- „ *Feistmanteli* Griesb.
- „ *Jacquini* Mojs.
- „ *Tyndalli* Mojs.
- „ *Renardi* Mojs.
- „ *Ludolfi* Mojs.

¹ E. v. Mojsisovics, Himálayan Foss., *Palæont. Ind.*, ser. XV, Vol. III, Pt. 1, p. 132.

² C. Diener, Note on some fossils from the Halorites limestone of the Bambanag cliff, *Records, Geol. Surv. of India*, Vol. XXXIV, 1906, p. 1.

- Parajuvavites minor* Mojs.
 „ *Brintoni* Mojs.
 „ *buddhaicus* Mojs.
 „ *Stoliczkai* Mojs.
Thetidites Guidonis Mojs.
 „ *Huxleyi* Mojs.
Griesbachites jandianus Mojs.
Martolites Krafftii Dien.
Tibetites Ryalli Mojs.
 „ *Murchisoni* Mojs.
 „ *Perrin-Smithii* Mojs.
Anatibetites Kelvini Mojs.
Paratibetites Bertrandi Mojs.
 „ *Geikiei* Mojs.
 „ *Adolfi* Mojs.
 „ *angustisellatus* Mojs.
 „ *Tornquisti* Mojs.
Helictites Atalanta Mojs.
Dittmarites Hindei Mojs.
Dionites cf. Asbolus Mojs.
Steinmannites Desiderii Mojs.
 „ *clionitoides* Mojs.
 „ *Noetlingi* Mojs.
 „ *undulatostratus* Mojs.
 „ *Lubbockii* Mojs.
Clionites Woodwardi Mojs.
 „ *Salteri* Mojs.
 „ *aberrans* Mojs.
 „ *spinosus* Mojs.
 „ *Hughesii* Mojs.
Sirenites Richteri Mojs.
 „ *elegans* Mojs.
 „ *elegantiformis* Dien.
Sandlingites Nicolai Mojs.
 „ *Archibaldi* Mojs.
Arcestes Leonardii Mojs.
Pinacoceras Metternichii Hauer.

- Pinacoceras parma* Mojs.
 „ *postparma* Mojs.
Bambanagites Dieneri Mojs.
 „ *Schlagintweiti* Mojs.
Placites Sakuntala Mojs.
Paranautilus bambanagensis Mojs.
Indonautilus Krafitti Mojs.¹
Clydonautilus biangularis Mojs.

The Halorites limestone is eminently a cephalopod horizon, in which ammonites predominate very considerably among the invertebrate fauna. The number of species of *Brachiopoda* and *Lamellibranchiata* which have been described by Bittner (l.c., p. 72), is very small. He mentions the following forms :—

- Rhynchonella bambanagensis* Bittn.
Halobia aff. *comata* Bittn.
Lima serraticosta Bittn.
Anodontophora Griesbachi Bittn.

The lowest noric horizon in Painkhanda is a complex of nodular and slaty limestones, from 70 to 100 feet in thickness, which succeeds the beds with *Halobia comata* in the Bambanag section and is overlain immediately by the fossiliferous layer of the Halorites beds. The small fauna consists of badly preserved cephalopoda, of which only a single species has been found worthy of a specific name. The rest are indeterminate fragments.

The following forms have been enumerated by E. v. Mojsisovics :—

- Proclydonautilus Griesbachi* Mojs.
Pinacoceras sp. ind. aff. *imperator* Mojs.
Hauerites sp. ind. (= *Metacarnites* Dien).
Arcestes sp. ind.
Sagenites sp. ind.
Juvavites sp. ind.
Parajuvavites sp. ind. aff. *Jacquini* Mojs.
 „ sp. ind.

¹ E. v. Mojsisovics, Die Cephalopoden der Hallstätter Kalke, *Abhandl. K. K. Geol. Reichsanst.*, VI-1, Supplem., p. 205.

Of brachiopods *Rhynchonella bambanagensis* has been mentioned by Bittner.

This group of nodular limestones, which lithologically recalls the Muschelkalk, was first designated "Hauerites beds" by E. v. Mojsisovics, a name which later on was replaced by "Zone of *Proclydonautilus Griesbachi*." The name "Hauerites beds" has become untenable, since Diener¹ has proved the fragments assigned to *Hauerites* by E. v. Mojsisovics to belong to a new subgenus, allied very nearly to the Alpine *Carnites floridus* Wulf.

d. Interregional correlation and homotaxis of the Upper Triassic deposits of Spiti and Painkhanda with those of Europe and America.

In Spiti the carnian stage opens with the Halobia limestone, but in its meagre fauna *Halobia cf. compta* Bittn. is the only fossil directly indicative of a carnian age. Whether it ought to be correlated with the cordevolic or julic substage of the Alpine Trias, cannot be decided. There is, indeed, no evidence of the cordevolic substage being represented faunistically in the Himalayas.

In the "Grey beds," following above the Halobia limestone, the lower fossiliferous horizon with *Joannites cymbiformis* Wulf. is certainly a homotaxial equivalent of the zone of *Trachyceras aonoides* of the julic substage in the Alps. Among six species of ammonites three are identical with European forms from this zone, and the rest, which could not be determined specifically, equally point in the same direction.

The brachiopod-bearing horizon of the grey beds, situated 300 feet above the basal fossiliferous layer, has yielded several elements peculiar to the Indian region, among them the genera *Lilangina*, *Pomaringina*, *Aspidothyris*. Among the species of *Brachiopoda* with European affinities, there are some remarkable types, which point more nearly to a Muschelkalk than to an Upper Triassic age. But all of them—especially *Mentzelia Mentzelii* Dunk.—range as stragglers into the julic substage of the Eastern Alps. There is no palæontological evidence in favour of a correlation of this horizon with the upper carnian or tuvalic substage.

¹ C. Diener, *Himál. Foss.*, Vol. V, Pt. 3, p. 108.

The homotaxial equivalent of the tuvalic substage or zone of *Tropites subbullatus* is found in the *Tropites* beds of Spiti. In this cephalopod horizon Indian faunistic elements are in a minority. European affinities predominate to a large extent. There is not a single genus in the fauna of the *Tropites* beds, which was not known from the carnic stage of the Alpine Trias. All elements, which are conspicuous for their fecundity and give to this fauna its peculiar aspect, are characteristic of the zone of *Tropites subbullatus* of the Hallstatt limestone. Eight species among 22 are identical or nearly identical with congeneric forms from the carnic stage of the Salzkammergut.

From this fauna noric elements are as completely absent as from its homotaxial equivalent, the tuvalic substage of Hallstatt and Aussee.

In the tuvalic substage the dolomitic limestone with *Halobia aff. superba* Mojs. must be included, the association of *Dielasma julicum* Bittn., *Halobia aff. superba* Mojs., *Daonella cf. styriaca* Mojs., *Lima cf. austriaca* Bittn. being characteristic of a carnic age.

In Painkhanda two carnic horizons, both rich in *Cephalopoda*, are known to us, both of them pointing to the julic substage.

The lower horizon is the *Traumatocrinus* limestone of the Shalshal and Bambanag cliffs. Its fauna was assigned to the julic substage in 1896 by E. v. Mojsisovics. This correlation was questioned by A. v. Krafft, but proved to be correct by Diener's examination of the rich fossil materials collected by A. v. Krafft in 1900.

The European affinities are marked very clearly in this fauna, eleven species being common to the Indian and Alpine regions, among them the most important and the most frequently occurring. There are only two genera, *Girtherias* and *Rimkinites* of exclusively Indian habit.

The *Traumatocrinus* limestone is overlaid conformably and immediately by a limestone bed containing *Daonella indica* Bittn. This bed must, consequently, be of julic age. From this fact it is evident that there is no distinct stratigraphical horizon in the Himálayas characterised by the presence of *Daonella indica*, as had been suggested by Bittner. This species has, on the contrary, a very wide stratigraphical distribution, ranging through the entire ladinic and the lower division of the carnic stage.

The beds with *Halobia comata* of Painkhanda and Johar—with the exception, however, of their uppermost layers—must also be included in the julic substage. The cephalopods described by E. v. Mojsisovics

exhibit a striking similarity to the fauna of the beds with *Lobites ellipticus* near Aussee. The genera *Anatomites*, *Griesbachites*, *Hypocladiscites* and *Styrites* are represented by species nearly allied in both areas. Among the *Lamellibranchiata*, *Halobia* of the group of *H. rugosa* are an important element characteristic of the Julic substage.

Both the *Traumatocrinus* limestone and the main mass of the beds with *Halobia comata* in the Bambanag and Shalshal cliffs must therefore be correlated with the Grey beds of Spiti.

The fauna of the *Tropites* beds has not yet been found in the sections of Painkhanda examined by Griesbach, Diener and A. v. Krafft, but we have strong evidence in favour of this horizon being represented there by the uppermost layers of the calcareous shales with *Halobia comata*. Nearly all the ammonites described by E. v. Mojsisovics were collected from the lower and middle divisions of this rock-group, whereas only one species with European affinities, *Mojsvarites eugyrus* Mojs., is known from the topmost beds, but this species has been found in Europe not only in beds of Julic age, but also in the zone of *Tropites subbullatus*.

It is not probable that no sediment at all was deposited in this region of the Himálayas during the tuvalic period. I prefer to agree with E. v. Mojsisovics in suggesting that the uppermost layers of the beds with *Halobia comata* underlying the nodular limestone with *Procydonautilus Griesbachi*, correspond with the *Tropites* beds and that their fauna will be discovered there some day, for cephalopods are not rare in this thick mass of shaly beds, but it is very difficult to secure them owing to their fragility.¹

Both the *Halobia* limestone and the dolomitic limestone with *Lima cf. austriaca* and *Halobia aff. superba* of Spiti are wanting in the more eastern sections. The tuvalic substage, with a thickness of about 900 feet in Spiti, is reduced to an insignificant band of calcareous shales in Painkhanda.

Of the two divisions, into which the noric stage of the Himálayas falls naturally in Spiti and Painkhanda, the upper one is developed

¹ The ammonites collected in the beds with *Halobia comata* in 1900 by A. v. Krafft belong chiefly to the genera *Juravites*, *Anatomites* and *Arcestes*, but do not admit of specific determination. The specimen of *Griesbachites Medleyanus* quoted in "Himálayan Fossils," Vol. V, Pt. 3, p. 152, has not been found in A. v. Krafft's collections.

very equally in both districts. The correlation of the noric beds underlying the Dachsteinkalk has been based on stratigraphical evidence by A. v. Krafft. The fauna is too indifferent, especially in Painkhanda, either to contradict or to support this evidence.

A. v. Krafft correlated the quartzite series, with *Spirigera maniensis* of Spiti with the corresponding series in Painkhanda, the Monotis beds of Mani and Lilang with the main layer of *Anodontophora Griesbachi* in the Bambanag cliff, where *Monotis salinaria* is, however, absent, the coral limestone of Spiti with the dolomitic limestone containing *Spiriferina Griesbachi* in Painkhanda. Those three rock-groups are rather poor in fossils and have a considerable number of faunistic elements in common. *Cephalopoda* are extremely rare. Two species of *Trachypleuraspides* from the Monotis beds of Mani and a fragment of *Sagenites* from the main layer of *Anodontophora Griesbachi* of the Bambanag cliff afford no clue to the geological age of those beds. The only species of stratigraphical importance is *Monotis salinaria* Schloth., which is also known to us from the Pamir and from the Pishin district, Baluchistan.

The cephalopod-bearing beds, which form the lower division of the noric stage, exhibit a different development in Painkhanda and Spiti. In Painkhanda two cephalopod horizons occur, the nodular limestone with *Proclydonautilus Griesbachi* and the Halorites limestone. In Spiti one single horizon only, the Juvavites beds, corresponds to them.

The nodular limestone with *Proclydonautilus Griesbachi* is very poor in fossils, but among those fossils two species of *Parajuvavites*, and one species of *Pinacoceras*, nearly allied to *P. imperator*, have been described by E. v. Mojsisovics, all of them types with decidedly noric affinities. A correlation of this nodular limestone with the dolomitic limestone, following above the Tropites beds of Spiti, is consequently impossible. The nodular limestone with *Proclydonautilus Griesbachi* has been considered by E. v. Mojsisovics as a horizon independent from the Halorites limestone both stratigraphically and faunistically, but the arguments put forward by this learned author are not convincing.

Regarding the great deficiency of fossil materials from the nodular limestone with *Proclydonautilus Griesbachi*, it cannot be decided whether the faunas of this horizon and of the overlying Halorites beds

represent one single or two distinct palæontological zones, although there is some evidence in favour of the latter alternative.

The richest Upper Triassic fauna in Painkhanda is included in the Halorites limestone. It contains 67 species of *Cephalopoda*, 61 of them determinable specifically. *Parajuvavites* and acatenate species of *Halorites* are the leading types. *Bambanagites* and *Guembelites*—both of them rare elements in this fauna—are of exclusively Indian habit. The Alpine genera *Metasibirites* and *Cyrtopleurites* are replaced by their Indian representatives *Thetidites* and *Tibetites*.

Four species are probably identical with forms from the noric Hallstatt limestone, namely:—

Pinacoceras Metternichii Hau.

„ *parma* Mojs.

„ *postparma* Mojs.

Dionites cf. Asbolus Mojs.

As has been demonstrated by E. v. Mojsisovics, the fauna of the Halorites limestone has relations with the faunæ both of the lower (lacic) and middle noric (alaunic) substages. But the preponderance of lacic elements, together with the absence of all types confined to the alaunic substage exclusively, is so obvious, that the lower noric or lacic age of the Halorites limestone can be established with certainty.

The fauna of the Juvavites beds of Spiti also bears the stamp of a lacic age, but does not show any close affinity to the fauna of the Halorites limestone. Three species only are identical, and two more very nearly allied, but those specific similarities are confined to forms which do not play any important part in the lower noric faunæ of Painkhanda or Spiti. *Halorites* and *Parajuvavites*, the two most prominent elements in the fauna of the Halorites limestone, have not been met with in Spiti, where they are replaced by species of *Juvavites*, which do not show any close affinity to the congeneric forms of the Alpine region. Although the lower noric cephalopod beds of Spiti and Painkhanda must be correlated, both for stratigraphical and palæontological reasons, their faunæ exhibit very distinct local peculiarities in both districts. This difference between the faunæ of the Juvavites beds in Spiti and the Halorites beds in the Bambanag section indicates a considerable change in the conditions of life since the end of the Muschelkalk epoch, the fauna of which is distinguished by a very

uniform character throughout the Mesozoic belt of the central Himálayas.

In Asia beds of Upper Triassic age are not distributed widely outside the Indian region. In Asia Minor the rhætic stage has been discovered by G. v. Bukowski.¹ The fauna, consisting chiefly of brachiopods and lamellibranchs, bears the stamp of an upper noric or rhætic Mediterranean fauna, but shows no affinity to the noric faunæ of the Himálayas.²

On the Island of Kotelny (New Siberia) Upper Triassic shales and marly limestones have been discovered by Baron E. Toll. A preliminary examination of the rich fauna has convinced me of its carnic age. The most important elements are *Ha'obia* of the group of *H. fascigera* Bittn. This is a decidedly Indian type in this Arctic fauna, which is not known from any other Arctic region, where Triassic sediments are developed in a bivalve facies (Eureka sound, Bears Island, Spitzbergen). *Cephalopoda* are very rare and represented in Baron Toll's collection by only a few specimens of *Cladiscites*, *Pinacoceras* (group of *P. rex* Mojs.) and *Arcestes*.³

In Western America the carnic stage is represented by the *Tropites* beds of the Hosselkus limestone in Shasta county, California. According to J. P. Smith⁴ the affinity of their rich fauna is much greater to the Mediterranean than to the Indian faunæ, although several species are probably common to both areas. The following species are directly or nearly identical :—

Tropites subbullatus Hau.

„ *torquillus* Mojs.

Trachysagenites Herbichi Mojs.

A considerable number of American carnic species are represented in India by forms, which are very closely related.

The association of *Tropites* and *Trachyceras* in California points to an early appearance of the *Tropitidæ* in America, where they

¹ G. v. Bukowski, Die geologischen Verhältnisse der Umgebung von Balia Maaden, etc., *Sitzgsber. Kais. Akad. Wiss. Wien*, CI. 1892, p. 214.

² A. Bittner, Triaspetrefakte von Balia Maaden in Kleinasien, *Jahrb. K. K. Geol. Reichsanst.*, XLI, (1891), p. 97, XLII, (1892), p. 77, XLV, (1895), p. 249.

³ *Lethæa mesozoica*, Vol. I, Trias, p. 542.

⁴ J. P. Smith, The stratigraphy of the Western American Trias, *l.c.*, p. 402.

probably originated. From this region they migrated into the Indian and Mediterranean Triassic provinces, where they make a sudden appearance without any local ancestors. But the path of this migration probably led into the Tethys by the way of the Atlantic rather than of the Pacific Ocean, since the affinities of the Californian carnic fauna are Alpine rather than Himálayan.

In the noric stage the affinities between the American and Indian faunæ are very remote. The fauna of *Pseudomonotis ochotica* Keyserl., which is probably identical with *Ps. subcircularis* Gabb, is widely distributed in Northern Asia and along the coasts on either side of the Pacific Ocean, but reached neither India nor the Alpine region. The exchange of faunistic elements between America and the Himálayas appears to have been suspended entirely during the noric period. It was probably resumed during the liassic epoch, as we may judge from the universal distribution of the genus *Arietites*, which is known from Europe, Western Asia, India, Timor, California, Nevada, Mexico, South America.

e. The Upper Trias of Kashmir and the Pamir.

α.—KASHMIR.

The researches on which our knowledge of the Upper Triassic deposits of Kashmir are based were carried out before the publication of C. L. Griesbach's memoir on the central Himálayas. Since Stoliczka's early reconnaissances and R. Lydekker's memoir on Kashmir (1883), no recent surveys have been made in that State although certain parts of Rupshu have been visited by Hayden and found to be stratigraphically almost identical with Spiti.

Naturally the data available for a description of the Upper Triassic deposits of Kashmir are therefore very scanty and very often antiquated. We are so far entirely in want of detailed stratigraphical data, while the fossils, which we know to have been derived from the Triassic beds of this area, are extremely small in number. This is all the more to be regretted, since Triassic beds are widely distributed in several isolated districts of Kashmir, chiefly in the Kashmir, Zanskar, Changchenmo, Karakoram and Baltistan basins (Lydekker: *Mem., Geol. Surv. Ind.*, XXII, pp. 133, 147, 154, 168, 169, 171, 182).

Detailed stratigraphical researches would no doubt yield most interesting results.

As to the stratigraphy of the Upper Trias of Kashmir, we only know that the thick limestone masses ("Para" limestone), which elsewhere form the base of the Spiti shales, are represented there also. It further appears from Lydekker's accounts (l.c., p. 168) that this limestone mass is underlain by sandy and shaly deposits, as is also the case in Spiti and Painkhanda. The lower division is said to contain *Monotis salinaria* Schloth., the upper one chiefly *Megalodon* and *Dicerocardium*.

Only three fossils belonging to the noric stage have so far been described :—

1. *Spirigera Noettingi* Bittn.¹ collected by Stoliczka from Nio Sumdo in Karnag, Zanskar basin, probably also from Pankpo Pass (Zanskar basin). The fossil was regarded as liassic by Stoliczka (*Memoirs, Geol. Surv. Ind.*, V, pp. 342, 345, 346).

This species is also known from the noric stage of Spiti and of the Bamnanag section.

2. *Megalodon cultridens* Bittn. (l.c., p. 62), collected by Stoliczka in the vicinity of Lingti Sumdo, probably a locality in the Lingti valley, Zanskar basin. This species has not yet been obtained from the Dachsteinkalk of Spiti.

3. *Megalodon ladakhensis* Bittn. (l.c., p. 65), from Shargol at the north-western termination of the Zanskar basin. It has been described and illustrated as *Megalodon cf. gryphoides* by Lydekker (l.c., p. 164, Pl. IV, figs. 1-4). This species also occurs in the Dachsteinkalk of Spiti.

To those three forms a few more may be added, the stratigraphical position of which is, however, somewhat doubtful.

One of them is *Dicerocardium himalayense* Stol., which Stoliczka (l.c., p. 342) records from the "Para" limestone in the section between Lahaul and Karag. It is according to his observations very common in the "Para" limestone of Ladakh and indicative of either Upper Triassic or liassic age. The type-specimen of *Dicerocardium himalayense* was collected east of Kioto in north-western Spiti. The forms, which are abundant in the "Para" limestone of Spiti, Ladakh and Rupshu, are

¹ A. Bittner, *Himál. Foss.*, Vol. III, Pt. 2, p. 68.

perhaps specifically different, as has been remarked by A. Bittner (l.c., p. 66).

Another species, which is probably derived from the noric beds of Kashmir, is *Monotis salinaria* Schloth., recorded from Khar (Zanskar basin) by Stoliczka (l.c., p. 345). That the species recorded by Stoliczka, is identical with the Alpine leading fossil of the noric Hallstatt limestone, is very probable, for it is known to occur both to the south-east and north-west of Kashmir. Among Stoliczka's collections from Shargol (north-western corner of the Zanskar basin) a few flags of grey limestone have been noticed by Suess, which seem to have been derived from the *Monotis* beds. The fossils are, however, badly preserved.

From the Upper Triassic limestones of the Karakoram Pass *Heterastridium* and *Stoliczkania* have been collected by A. le Coq.¹

β.—PAMIR.

Stoliczka, when about to return to India from Chinese Turkestan, whither he had accompanied the second Yarkand Mission, traversed the eastern Pamir and obtained some very interesting geological results. A record of the Triassic fossils collected by him, is contained in a paper by Prof. E. Suess "Zur Stratigraphie Centralasiens."²

Near Aktash Stoliczka observed the following sequence of beds, in descending order :—

4. Black, crumbling shales, with intercalated limestones, containing *Halorella*.
3. Grey shales.
2. Brownish sandstone, somewhat silicious.
1. Limestone.

The limestone beds intercalated between the black shales (No. 4) have yielded the following species :—

Halorella rectifrons Bittn.

„ *Stoliczkai* Suess.

¹ P. Oppenheim, Ueber von Herrn A. le Coq gesammelte Heterastridien vom Karakoram Pass *Centralbl. f. Min., etc.*, 1907, p. 722.

² *Denkschriften Kais. Akad. d. Wissench.*, 1894. Bd. LXI, pp. 432-466.

Halorella pedata Bronn.

Monotis salinaria Schloth.

Thamnastraea rectilamellosa Winkl.

Of those five species only *Monotis salinaria* is known to occur in the Central Himálayas of Spiti. It was first discovered by H. Hayden near Mani on the Spiti river in 1899, where it abounds in a grey, shaly limestone. It was also observed in the section of Lilang by A. v. Krafft, where it is, however, much rarer.

The rock in which it occurs in Spiti is very similar to that of the Pamir. According to A. v. Krafft's notes hand-specimens from the one locality can scarcely be distinguished from those from the other.

Species of *Halorella* are as yet unknown from the Himálayas proper, but have been found in the south-eastern area of the Indian province, namely, in the Upper Trias of the Malayan archipelago.

f. *The Upper Trias of Byans.*

The Upper Trias of Byans differs considerably from that of Johar, Painkhandia and Spiti. Very little, however, is known at present about its fossiliferous horizons. The country has not yet been surveyed in detail, owing to the difficulty of a correct interpretation of the different sections, which appear to be so intensely crushed and disturbed that an exact determination of the single horizons, which lithologically resemble each other most closely, becomes almost an impossibility.

Only the general sequence of the beds has been ascertained by F. H. Smith in 1899 and by A. v. Krafft in 1900 during their short visits to the district.

The blue-grey limestone, 250 feet in thickness, which follows above the chocolate limestone of Lower Triassic age, has yielded the fauna of *Spiriferina Stracheyi* 70 feet above its base and, in the beds immediately above this brachiopod-bearing horizon, numerous cephalopods characteristic of the Upper Muschelkalk.

The next fossiliferous layer is situated in the topmost bed of this blue-grey limestone. This is the famous "Tropites limestone" of Kalapani with its strange association of carnic and noric types. In the upper portion of the blue-grey limestone the entire ladinic and carnic

stage must, consequently, be included. A very marked decrease in the thickness of Middle and Upper Triassic sediments certainly takes place from Johar towards Byans. Supposing even that the ladinic stage is completely absent, as we may infer from its reduced thickness in the Niti area, and that accordingly the thickness of the carnic stage amounts to 170 feet in the section of Kalapani, this is considerably inferior to that of the equivalent beds in Painkhanda and Johar. The proportions are expressed in feet :—

Spiti (maximum thickness)	1,290 feet.
Painkhanda and Johar (maximum thickness)	820 „
Byans.	170 „

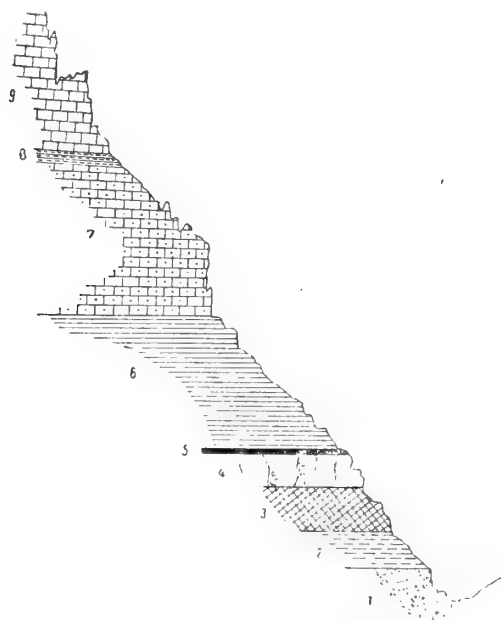


FIG. 11.—Section N. W. of Kalapani (Byans) (from A. v. Krafft's diary)

9. Megalodon limestone.
8. Shales with indeterminable ammonites.
7. Grey limestone.
6. Black shales with *Arcestes*.
5. Tropites limestone.
4. Light grey limestone (Muschelkalk, ladinic and carnic stage)
3. Chocolate limestone (Lower Trias).
2. Productus shales (Permian).
1. White Quartzite.

This decrease of the carnic stage from N. W. to S. E. is intimately connected with a change of facies. The shaly deposits of the horizon of *Halobia comata* in the Bambanag section are replaced in Byans by pure grey limestones, in which no trace of shaly layers has been found. It would be an interesting task to search for the connecting links between the different facies of the two areas, which must pass into one another somewhere between Johar and Byans.

The rich fauna of the Tropites limestone showing an assemblage of carnic and noric elements, all the higher beds following above, must be assigned to the noric stage.

In the district to the north of the Kali and Kuti Yangti rivers A. v. Krafft distinguishes the following sequence of beds above the Tropites limestone :—

4. Series of limestones (not examined in detail).
3. Shales with undeterminable ammonites.
2. Grey limestone of great thickness.
1. Black shales with *Arcestes sp.* : about 1,000 feet.

F. H. Smith in his generalized section of the Triassic rocks observed in Byans, distinguishes a larger number of rock-groups, according to the colours of the blue-grey limestone exhibited on weathered surfaces. But, broadly speaking, two main divisions can be recognised, a lower consisting of dark shales, and an upper, about 1,500 feet in thickness, in which limestones predominate. The shaly band No. 3 has been observed in the section of Kalapani only, where it is strongly crushed.

The occurrence of shaly deposits, 1,000 feet thick, in the lower division of the noric stage, once more emphasizes the dissimilarity of the Upper Triassic beds developed in Byans to those of Johar and Spiti. On the other hand the upper division of the noric (rhætic?) beds of Byans seems to agree with that of the districts described above, consisting, as it does, of a thick limestone series extending from the Upper Trias into the Jurassic system and overlain by the Upper Jurassic Spiti shales. As is evident from F. H. Smith's notes, the ferruginous oolites of the *Sulcacutus* beds form a constant and well marked horizon on the top of the limestone series No. 4 both here as well as in the more north-westerly districts.

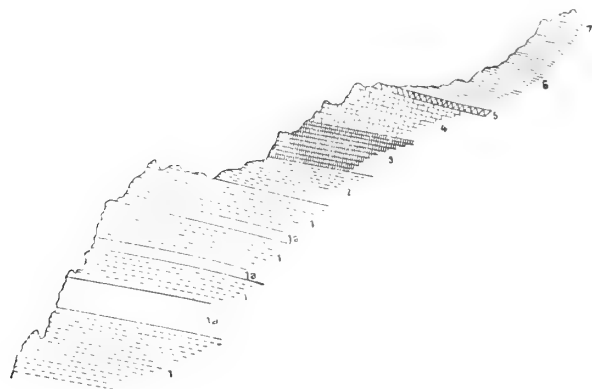


FIG. 12.—Section along the route from Kalapani to Nabi (from A. v. Krafft's diary).

- | | |
|--|----------------|
| 7. Grey limestone | } Noric stage. |
| 6. Shales | |
| 5. Tropites limestone. | |
| 4. Light grey limestone (Muschelkalk, ladinic (?) and carnic stage). | |
| 3. Chocolate limestone (Lower Trias). | |
| 2. Productus (Kuling) shales (Permian). | |
| 1. Brown quartzite. | |
| 1a. White quartzite. | |

A. v. Krafft discovered several fragments of ammonites in the top-most beds of the grey limestone (No. 2) and in the overlying shales (No. 3). Their similarity with forms from the zone of *Proclydonautilus Griesbachi* and from the Halorites limestone of the Bambanag section induced him to venture on a correlation of the shales No. 3 with the Halorites beds of Painkhanda. But the specimens in A. v. Krafft's collections are all indeterminable fragments, which do not even permit of generic identification. Moreover, the correlation with the Halorites limestone is contradicted by the zoological character of the Tropites limestone. For the present moment we are not able to say anything definite about the probable correlation of the Upper Triassic beds of Byans following above the Tropites limestone.

The only fossiliferous horizon of Upper Triassic age in Byans which is distinguished by a rich and characteristic fauna is the *Tropites* limestone. Among the fossils discovered by C. L. Griesbach near Kalapani,

but assigned erroneously to the lias, representatives of the carnian genus *Tropites* were recognised by E. v. Mojsisovics.¹ Very extensive materials were collected by F. H. Smith and A. v. Krafft from Kalapani, Tera Gadhi, Lilinthe, Nihal and Kuti. The following species have been described by C. Diener:²—

- Rhynchonella angulifrons* Bittn.
Halobia cf. *fascigera* Bittn.
 „ cf. *comata* Bittn.
Avicula sp. ind. aff. *caudata* Stopp.
 „ „ *Tofanæ* Bittn.
Atractites cf. *ellipticus* Mojs.
 „ cf. *convergens* Hau.
Orthoceras cf. *triadicum* Mojs.
 „ cf. *dubium* Hau.
Grypoceras sp. ind. aff. *mesodico* Hau.
Proclidonautilus *Griesbachiformis* Dien.
Pinacoceras *parma* Mojs.
 „ *Metternichii* Hau.
 „ cf. *rex* Mojs.
 „ *Beecheri* Dien.
Placites *polydactylus* var. *Oldhami* Mojs.
 „ sp. ind. aff. *peraukti* Mojs.
Bambanagites *Krafftii* Dien.
Carnites cf. *floridus* Wulf.
Monophyllites *Jarbas* Muenst.
Discophyllites *Ebneri* Mojs.
Arcestes *dicerus* Mojs.
 „ *bicornis* Hau.
 „ *subbicornis* Mojs.
Proarcestes cf. *Gaytani* Klipst.
 „ sp. ind. ex. aff. *Zitteli* Mojs.
 „ cf. *Sturi* Mojs.
 „ sp. ind. aff. *sublabiati* Mojs.

¹ E. v. Mojsisovics, Vorläufige Bemerkungen ueber die Cephalopodenfauna der Himalaya Trias, *Sitzgsber. Kais. Akad. d. Wiss.*, Cl. Mai 1892.

² C. Diener, The fauna of the Tropites limestone of Byans, *Himal. Foss.*, Vol V, Pt. I.

- Cyrtopleurites Freshfieldi* Dien.
 „ *sp. ind. aff. Agrippinæ* Mojs.
Tibetites cf. Ryalli Mojs.
Anatibetites Kelvini Mojs.
 „ *Hobsoni* Dien.
Paratibetites Adolphi Mojs.
 „ *cf. Bertrandi* Mojs.
 „ *cf. Geikiei* Mojs.
 „ *sp. ind. aff. Tornquisti* Mojs.
 „ *Wheeleri* Dien.
Acanthinites Hogarti Dien.
Himavatites Watsoni Dien.
Polycyclus Henseli Opp.
Clionites gracilis Dien.
 „ *sp. ind. aff. Hughesii* Mojs.
 „ „ „ *aberrans* Mojs.
 „ „ „ *Dolloanus* Mojs.
 „ *Stauntoni* Dien.
Protrachyceras Ansoni Dien.
Sandlingites cf. Oribasus v. Dittm.
 „ *Pearsoni* Dien.
 „ *Tuckeri* Dien.
 „ *sp. ind. aff. Archibaldi* Mojs.
Sirenites trachyceratoides Dien.
 „ *sp. ind. aff. Kohanyi* Mojs.
 „ *Pamphagus* v. Dittm.
 „ *Agriodus* v. Dittm.
 „ *cf. Argonautæ* Mojs.
 „ *sp. ind. aff. Argonautæ* Mojs.
 „ *argonautæformis* Dien.
 „ *cf. Dianæ* Mojs.
 „ *Ecæ* Mojs.
 „ *Alixis* Dien.
 „ *Vredenburgi* Dien.
 „ *sp. ind. aff. Vredenburgi* Dien.
Anasirenites cf. Menelaus Mojs.
 „ *Greeni* Dien.

- Distichites Sollasii* Dien.
 „ *Falconeri* Dien.
 „ *sp. ind. aff. megacantho* Mojs.
 „ „ „ *celtico* Mojs.
 „ „ „ *Atropus* Dittm.
 „ „ „ *Minos* Mojs.
 „ *cf. Harpalos* Dittm.
 „ *Younghusbandi* Dien.
 „ *sp. ind. aff. Younghusbandi* Dien.
 „ *Reynoldsi* Dien.
 „ *ectolciticiformis* Dien.
Ectolcites Hollandi Dien.
 „ *arictiformis* Dien.
 „ *Duncani* Dien.
 „ *sp. ind. aff. Hochstetteri* Mojs.
Isculites Smithii Dien.
 „ *Heimi* Mojs.
 „ *sp. ind. aff. obolino* Dittm.
Halorites sp. ind. aff. procyon Mojs.
Jovites daciformis Dien.
 „ *spectabilis* Dien.
Gonionotites Gemmellaroi Dien.
Parajuvavites Jacquinii Mojs.
Anatomites speciosus Dien.
 „ *cf. crasseplicatus* Mojs.
 „ *cf. Fischeri* Mojs.
 „ *cf. Theodori* Mojs.
 „ *cf. Edgari* Mojs.
 „ *Beresfordi* Dien.
Didymites tectus Mojs.
 „ *Kitchini* Dien.
 „ *sp. ind. aff. Quenstedti* Mojs.
 „ „ „ *subglobus* Mojs.
Metasibirites Philippii Dien.
Discotropites Krafftii ien.
 „ *Mojsisovicsi* Dien.
 „ *cf. sandlingensis* Hau.

- Margarites cf. auctus* Dittm.
 „ *nov. sp. ind. aff. aucto* Dittm.
 „ *Georgii* Mojs.
 „ *sp. ind. aff. Georgii* Mojs.
 „ *cf. circumspinitus* Mojs.
 „ *Sushena* Dien.
 „ *Devasena* Dien.
Tropites subbullatus Mojs.
 „ *cf. fusobullatus* Mojs.
 „ *cf. discobullatus* Mojs.
 „ *cf. Estellæ* Mojs.
 „ *sp. ind. aff. acutangulo* Mojs.
 „ *Wodani* Mojs.
 „ *cf. Paracelsi* Mojs.
 „ *Jalandhara* Dien.
 „ *Manasa* Dien.
 „ *kalapanicus* Mojs.
Anatropites nihalensis Dien.
 „ *margaritiformis* Dien.
Paratropites lilinthicus Dien.
Tropiceltites arietitoides Dien.

To this list several forms must be added, belonging to the genera *Loxonema*, *Orthoceras*, *Lobites*, *Thisbites*, *Dittmarites*, *Trachyceras*, *Protrachyceras*, which did not permit of specific determination.

There are on the whole 168 species known up to the present time from the *Tropites* limestone. Not less than 155 species are ammonites. Among them 102 are peculiar to this horizon, whereas 53 are identical with species either from the Alpine Hallstatt limestone or from the Halorites beds of the Bambanag section. But a very large percentage of the species peculiar to the *Tropites* limestone are nearly allied with Alpine types. Thus the relations with Upper Triassic faunæ of the Mediterranean region are very strongly marked.

As faunistic elements peculiar to the Indian Triassic region the following must be mentioned:—*Jellinekites*, *Trachypleuraspides*, *Himavatites*, the groups of *Sirenites Vredenburgi*, *Drepanites Schucherti*, *Clionites gracilis*, *Distichites ectoliticiformis*, *Tropiceltites arietitoides*, *Anatropites margaritiformis*. Their number is, however, less considerable

than the large percentage of species, which are nearly allied to European forms.

Many important types point to the carnica stage and are indicative of a homotaxis with the Alpine zone of *Tropites subbullatus*. But a second faunistic element pointing to the noric stage is almost equally distributed in the Tropites limestone. Not less than 49 species of ammonites are either identical or very closely allied with species from the noric Hallstatt limestone or (13) from the Halorites beds. A. v. Krafft was the first author to notice this strange assemblage of carnica and noric types in one single bed of limestone only three feet thick.

It might be suggested that this fauna marks a transitional stage bridging over the faunistic hiatus, which exists between the carnica and noric stages of the Eastern Alps. But Diener remarks that such faunistic elements as might be regarded as transitional forms connecting the two faunæ are missing, and that the species present in variably show distinctly carnica or noric affinities. He consequently denies the possibility of considering the Tropites limestone as a true passage bed from the carnica to the noric stage.

He further insists on the remarkable similarity of the strong admixture of carnica and noric types in the Tropites limestone of Byans with the remarkable association of Kelloway and Oxford ammonites in the Jurassic oolites of Balin (Galeiia), which has been explained by Neumayr by a want of sediment during that period. The association of carnica and noric faunæ in the Tropites limestone of Byans might also be explained by the want of sediment during the tuvalic and latic periods. In this case the bed of the Tropites limestone although only three feet in thickness, might represent equivalents of the topmost division of the beds with *Halobia comata*, of the limestone with *Proclidonautilus Griesbachii* and of the Halorites beds of the Bambanag section. The want of sediment would be the real cause of the enormous fecundity of this thin layer in ammonites with carnica and noric affinities.

The correctness of this explanation has yet to be proved by the results of a detailed survey of the Upper Triassic rocks of Byans.

IV.—SUMMARY.

The two best known areas in the Triassic belt of the Himálayas are Spiti and Painkhanda. The sections of Byans are known to us in

general outlines, whereas from Kashmir and Ladakh only isolated data are as yet available.

1. Lower Trias and Muschelkalk are developed almost equally well in Spiti on the one hand and in Painkhanda on the other. The lower Trias contains at least three separate faunæ, namely, the *Otoceras-Ophiceras* fauna, the *Meekoceras* fauna, and the *Flemingites-Hedenstræmia* fauna. To this must be added the *Sibirites* fauna, which is hitherto known with certainty from Byans only. Subdivisions of the Lower Trias must therefore be based on those clearly marked palæontological horizons. The former subdivision into *Otoceras* beds and *Subrobustus* beds must be abandoned, since the genus *Otoceras* is confined to a thin layer at the base of the lower Trias, while *Ceratites subrobustus* (= *Keyserlingites Dieneri* Mojs.) belongs exclusively to the Lower Muschelkalk.

The Muschelkalk naturally falls into three subdivisions. The lower division consists of a nodular limestone poor in fossils, which is underlain by a brachiopod-bearing layer with *Rhynchonella Griesbachi*. The middle division (zone of *Spiriferina Stracheyi*) contains the fauna of *Keyserlingites Dieneri* (*Ceratites subrobustus* antea). The Upper Muschelkalk is very rich in cephalopods and represents, indeed, the richest and most widely spread fossil horizon of the Himālayas.

In Byans Lower Trias and Muschelkalk show a development different to that found in the other districts. The Muschelkalk consists of a much purer limestone facies than is the case to the north-west of that district. Faunistically, however, Lower Trias and Muschelkalk of Byans do not differ considerably from the equivalent beds of Spiti and Painkhanda. The topmost beds of Lower Triassic age contain the fauna of *Sibirites spiniger* which is probably homotaxial with that of the Upper Ceratite limestone in the Salt Range.

2. A strongly marked difference in thickness and lithological character sets in in the ladinic stage. While this stage is rich in fossils and of considerable thickness in Spiti, it is thin and poor in fossils in Painkhanda. Further to the east the ladinic stage has not yet been traced.

3. The marked difference just referred to is equally prominent in the carnic deposits. These are rich in shaly beds and very thick in Spiti, but dwindle considerably towards the east till in Byans their thickness is almost insignificant. At the same time the shales disappear and their place is taken by pure limestones.

In the carnic stage two ammonite faunæ can be distinguished, an upper with *Tropites subbullatus*, and a lower one with *Joannites cymbiformis*. The *Tropites* fauna has not yet been found in Painkhanda and Johar.

4. The noric deposits are, in their lower and middle divisions, richer in limestones and contain more natural rock groups in Spiti than in Painkhanda and Johar. They are divided into three groups of beds :—

Quartzite series.

Brachiopod beds.

Cephalopod beds.

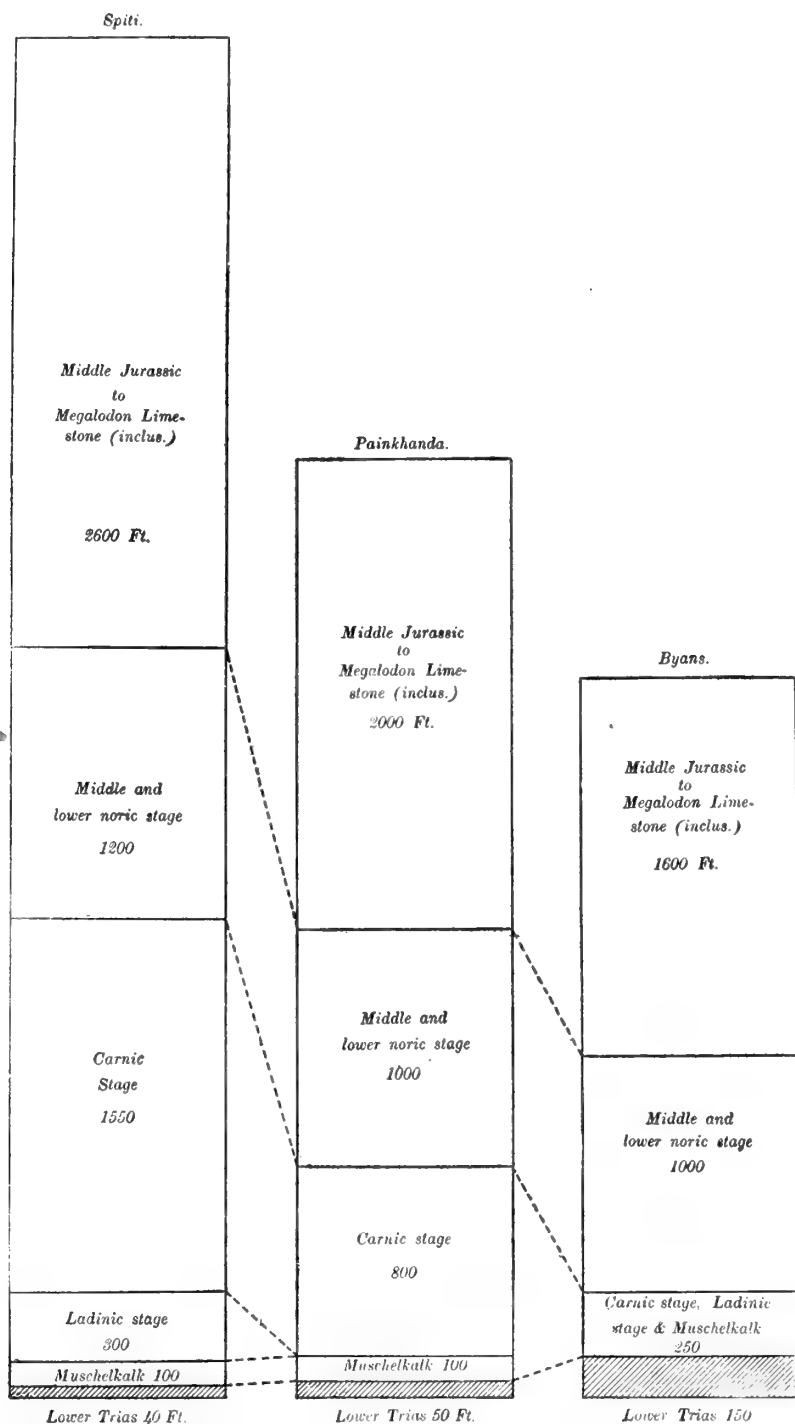
Locally the cephalopod beds are very rich in fossils in Johar (Bambanag cliff). But these beds (Halorites limestone) form no such constant stratigraphical horizon as the Muschelkalk.

The lower noric beds of Byans show peculiar features, being made up of black shales of great thickness, which are wanting in the other districts known.

Everywhere in the Himálayas the upper noric beds as far as we know consist of thick limestones and pass through beds of doubtful age into limestones of middle Jurassic age, which are overlain by the Upper Jurassic Spiti shales. From Spiti to Byans throughout the Mesozoic belt of the Himálayas a ferruginous oolitic layer (*Sulcacutus* beds) occurs at the base of the Spiti shales and constitutes a very constant horizon (Kelloway) in the Mesozoic deposits of the Himálayas.

The following table shows the relative thickness of the beds between the *Productus* shales and Spiti shales. It illustrates the remarkable decrease in thickness from north-west to south-east.

The second table gives a classification of the Triassic series of Spiti, Painkhanda, Johar and Byans. This table shows clearly that more detailed researches will have to be carried out before we can correlate the Trias of Byans in any detail with that of the other two districts. The Trias of Kashmir is so little known, that not even a rough outline of the stratigraphical sequence can be given.



Eastern Alps.		Spiti.	Thickness (feet).	Painkhanda.	Thickness (feet).	Byans.	Thickness (feet).
Upper	•	Megalodon limestone	•	Megalodon limestone	•	Megalodon limestone.	•
Middle	•	Quartzite series (<i>Spirigera maniensis</i>) Monotis beds (<i>Monotis salinaria</i>) Coral limestone (<i>Spiriferina Griesbachi</i>)	300 • 300 • 100	Quartzite series (<i>Spirigera maniensis</i>) <i>Anodontophora Griesbachi</i> beds (Sagenites beds) Limestone with <i>Spiriferina Griesbachi</i> .	250 160 320	Greenish, black shales with sandy bands.	1,000
Lower	•	Juvavites beds	500	Holorites beds Nodular limestone with <i>Procladonanthus Griesbachi</i> .	200 100	•	•
Tuvalic	•	Dolomitic limestone (<i>Lima cf. austriaca</i>) Tropites shales (<i>Tropites cf. subbullatus</i>)	300 600	•	•	Tropites limestone.	•
Julic	•	Grey beds Higher beds with brachiopods and bivalves (near base <i>Joannites cymbiformis</i>). Halobia limestone (<i>Halobia omata</i>)	500 • 150	Beds with <i>Halobia comata</i>	800	Grey, massive lime- stone.	250
Cordevolic	•	Daonella limestone	•	Traumatocrinus limestone	25	•	•
Carnic stage.							
Upper Trias.							
Noric stage.							

Ladinic stage	Higher beds with <i>Daonella indicata</i> , near base <i>D. Lommeti</i> .	150	Passage beds of the Shal-shal cliff.	10—20	
	Daonella shales (<i>Daonella Lommeti</i>)	160			
Middle Trias.	Muschelkalk		Upper Muschelkalk (<i>Ptychites rugifer</i>) Beds with <i>Spiriferina Stracheyi</i> and <i>Keyserlingites Dieneri</i> .	100	<i>Ceratites Thuillieri</i> .
	Nodular limestone		Niti limestone		<i>Spiriferina Stracheyi</i> .
	Shaly bed with <i>Rhyachonella Griesbachii</i> .		Shaly bed with <i>Rhyachonella Griesbachii</i> .		Limestone with <i>Rhyachonella Griesbachii</i> .
Campil beds	Hedenstrœmia beds (<i>Flemingites Rohilla</i>)		Hedenstrœmia beds (<i>Flemingites Rohilla</i>)		<i>Sibirites spiniger</i> near top.
Lower Trias.	Seis beds	40	Meekoceras beds (<i>Meekoceras Faraha</i>)		Chocolate limestone 150
	Ophiceras bed (<i>Ophiceras Sakuntala</i>)		Ophiceras bed (<i>Ophiceras Sakuntala</i>)		
	Otoceras bed (<i>Otoceras Woodwardi</i>)		Otoceras beds (<i>Otoceras Woodwardi</i> , <i>Ophiceras Sakuntala</i>).		
Permian	Kuling or Productus shales		Kuling or Productus shales		Kuling or Productus shales.

B. Tibetan Facies.

The discovery of exotic blocks in Malla Johar by C. L. Griesbach, C. Diener and C. S. Middlemiss in 1892 acquainted us with a region situated to the north of the main Mesozoic belt of the Himálayas, in which a rapid change of facies takes place. The Permian and Triassic strata as exhibited in those exotic blocks show a development differing from that of the corresponding beds in the normal sections of Spiti, Painkhanda and Byans.

The facts stated by this expedition¹ were corroborated by A. v. Krafft's exploration of the exotic blocks in the neighbourhood of the Balchdhura in 1900. A. v. Krafft found a fairly complete sequence of Permian, Triassic and even liassic beds in the exotic blocks of Malla Johar, but he noticed that every single horizon was represented by beds of comparatively small thickness and belonging to a facies quite different from that of the beds of corresponding age in the Bamba-nag and Shalshal cliffs, notwithstanding their short distance apart of scarcely ten miles. The former A. v. Krafft termed the *Tibetan* and the latter the *Himálayan* facies.²

Evidence has been obtained of the representation of the following Triassic horizons:—

a. Lower Trias.

A large block of a dark red, earthy limestone, thin bedded, with a few grey layers, near the Kiogarh-Chitichun Pass (17,900 feet), marked E. B. No. 20 on the map accompanying A. v. Krafft's memoir, has yielded the following species of ammonites:—

Meekoceras joharense Krafft.

„ *infrequens* Krafft.

„ *jolinkense* Krafft.

Xenodiscus cf. nivalis Dien.

Hedenstræmia cf. byansica Krafft.

¹ C. Diener, *Ergebnisse*, l.c., pp. 588-607, and *Mem., Geol. Surv. of India*, Vol. XXVIII, pp. 1-27. C. L. Griesbach, Notes on the Central Himálayas, *Records, Geol. Surv. of India*, Vol. XXVI, Pt. I, 1893, pp. 19-25, and “On the exotic blocks of the Himálayas,” *Compte rendu de la IX session du Congrès Geol. internat. Vienne*, 1900, pp. 547-552.

² A. v. Krafft, Notes on the exotic blocks of Malla Johar in the Bhot Mahals of Kumaon, *Mem., Geol. Surv. of India*, Vol. XXXII, Pt. 3, pp. 127-183.

In number of individuals *Meekoceras joharensense* predominates. A fragmentary specimen of *Meekoceras* from the Hedenstrœmia beds of Banna, *e.g.* in Spiti, has been identified with this species by A. v. Krafft, although its state of preservation is too bad to warrant a safe identification. *Xenodiscus nivulis* and *Hedenstrœmia cf. byansica* suggest a correlation with the Hedenstrœmia stage of the Himálayan series. *Meekoceras jolinkense*, which is also known from the chocolate limestone of Byans and from the horizon of *Meekoceras lilangense* in Spiti, points to the lower division of the Lower Trias.

The fauna of the exotic block No. 20 is certainly of Lower Triassic age, although its correlation with the Hedenstrœmia beds as advocated by A. v. Krafft cannot be considered to be established with full certainty.

From the Chitichun area exotic blocks of Lower Triassic age have not been recorded.

The fossils included in the exotic block No. 20 do not exhibit any affinities with the Alpine Lower Trias, but agree entirely with those from the Himálayan region. Local faunistic peculiarities, which have been mentioned by A. v. Krafft (*l.c.*, p. 141, note) are of very slight importance only. But there is a very sharp lithological contrast, the Lower Trias of the Tibetan series consisting of dark red limestone recalling the Hallstatt limestone in the Mediterranean region.

b. Muschelkalk.

The Middlemiss crag near Chitichun No. I (17,740 feet), consisting of a small number of blocks of a red or red and white limestone, contains a rich fauna of ammonites, which were described by C. Diener in 1895.¹

In the following list such species only have been included as admitted of a specific determination :—

Ceratites (Danubites) Kansa Dien.

„ „ *Ambika* Dien.

Sibirites Pandya Dien.²

¹ *Pal. Ind.*, ser. XV, Himal. Foss., Vol. II, Pt. 3, The Cephalopoda of the Triassic limestone crag of Chitichun.

² The reference of this species to the genus *Sibirites* is accepted by E. v. Mojsisovics with some reserve (Himálayan Foss., Vol. III, Pt. 1, p. 51).

- Monophyllites Confucii* Dien.
 „ *Pradyumna* Dien.
 „ *Pitamaha* Dien.
 „ *Hara* Dien.
 „ *Kingi* Dien.
Procladiscites Yasoda Dien.
Xenaspis Middlemissii Dien.
Japonites Ugra Dien.¹
Sturia mongolica Dien.

To the same Triassic horizon as the Middlemiss crag two more exotic blocks in the Chitichun region must be assigned. One of them is situated near the low pass west of the peak Chitichun No. I, on the route from the Kiogarh Chaldou Pass to Chitichun E. G., and the second north of Lochambelkichak E. G., near the pass which leads into the valley of the Chaldou river. Both of them have yielded *lumachellæ* of *Xenaspis* and *Monophyllites*.

The presence of this horizon in the Balchdhura district is doubtful. Some badly preserved ammonites (*Procladiscites* cf. *Yasoda* Dien.?) in a loose block point to the fauna of the Middlemiss crag, according to A. v. Krafft.

Judging from its zoological character, the fauna of the Middlemiss crag was correlated with the Muschelkalk by Diener in 1895. He considered this limestone to form a lower division of the Indian Muschelkalk than the beds with *Ptychites rugifer* and *Ceratites Thuillieri* in the sections of the Bambanag and Shalshal cliffs, the predominating types showing all a somewhat lower character of development than in the geologically oldest congeneric forms from the Upper Himalayan or Alpine Muschelkalk.

When this fauna was examined by Diener in 1895, the Lower Muschelkalk age of the isolated Middlemiss crag had to be decided by its fossil contents only. This correlation was afterwards fully confirmed by A. v. Krafft's discovery of the fauna of the Middlemiss crag in the zone of *Spiriferina Stracheyi* and *Keyserlingites Dieneri* in the normal

¹ Referred to *Gymnites* originally. It has been demonstrated by E. v. Mojsisovics (Cephal. der Hallstaetter Kalke, *Abhandl. K. K. Geol. Reichsanst.*, VI 2, Supplem., p. 323), that it combines the shape and sculpture of *Xenaspis* with the sutures of *Japonites* and should be included in the latter genus.

sections of Spiti and Painkhanda.¹ This zone has the following species of ammonites in common with the fauna of the Middlemiss crag :—

Ceratites (Danubites) Kansa Dien.

Japnites Ugra Dien.

Monophyllites Kingi Dien.

„ *Hara* Dien.

„ *Confucii* Dien.

„ *Pradyumna* Dien.

The presence of those species in the Lower (or middle) Muschelkalk of the main belt of the Himalayas satisfactorily proves the correctness of a correlation, which had been based on palæontological evidence only.

The fauna of the Middlemiss crag exhibits only small affinities with the Alpine Muschelkalk and with the beds corresponding in age from Ismid² in Asia Minor, but resembles much more nearly that of the zone of *Spiriferina Stracheyi* in the Himalayan region, although the local faunistic peculiarities are marked more distinctly than in the Lower Trias. The preponderance of *Ammonaea leiostroca* (*Cladiscites*, *Monophyllites*) with the simultaneous diminution of *Ceratitoidea* is of special importance.

There is still the same lithological contrast prevailing between the Tibetan and Himalayan facies in both areas.

c. Lower Carnic stage.

A dark red, very ferruginous limestone of the exotic block No. I in A. v. Krafft's map (S. E. of Balchdhura No. II) has yielded *Daonella indica* Bittn. and *Halobia sp. ind.* No definite age can be assigned to this scanty fauna. *Daonella indica* ranges from ladinic into carnic beds, but the presence of a true *Halobia* is rather in favour of a carnic age.

d. Carnic stage.

The credit of the first discovery of an exotic block of this age is due to C. L. Griesbach, C. Diener and C. S. Middlemiss, who in 1892 collected some specimens of Upper Triassic ammonites in a red marble near

¹General Report, Geol. Surv. of India, for 1899-1900, p. 205.

²F. Toulà, Eine Muschelkalk fauna am Golf von Ismid in Kleinasien, *Beitrage zur Geol. u. Palæontol. Oesterreich-Ungarns*, etc., X, p. 189.

Sangeha Talla encamping ground. The ammonites were shown by E. v. Mojsisovics (l.c., p. 18) to belong to a species of *Jovites* closely allied to *J. bosnensis* Mojs.

In the district of Malla Johar the presence of two exotic blocks of middle or upper carnic age was ascertained by A. v. Krafft. One of those blocks (No. 5) near Malla Kiogarh encamping ground was of very small size. It consisted of a massive, much altered, red limestone and yielded fragments of *Carnites* sp. ind. and of *Proarcestes* sp. ind. ex aff. *ausseano* Hauer. Those remains, although very scanty, are sufficient evidence of a carnic age.

The second exotic block (No. 2) was discovered by A. v. Krafft one mile to the north-west of the Balchdhura Pass. From a bright red marble agreeing very closely with the carnic Hallstatt limestone of the Roethelstein near Aussee, the richest Mesozoic fauna of the Tibetan facies has been obtained. It consists of the following species, which have been described by C. Diener¹ :—

Dictyoconites nov. sp. ind. aff. *Haueri* Mojs.

Proclydonautilus triadicus Mojs.

„ *Buddhaicus* Dien.

Grypoceras suessiiforme Dien.

Mojsvaroceras sp. ind. aff. *Turneri* Hyatt et Smith.

Cladiscites crassestriatus Mojs.

„ cf. *Gorgiæ* Gemm.

„ sp. ind. cf. *coracis* Gemm.

„ cf. *pusillus* Mojs.

Hypocladiscites subcarinatus Gemm.

„ *subaratus* Mojs.

Arcestes cf. *periolcus* Mojs.

„ cf. *Richthofeni* Mojs.

„ sp. ind. aff. *decipiens* Mojs.

„ cf. *placenta* Mojs.

Proarcestes Gaytani Klipst.

„ cf. *ausseanus* Hau.

„ sp. ind. aff. *Barrandei* Lbe.

Discophyllites Floweri Dien.

¹ C. Diener, Upper Triassic and liassic faunæ of the exotic blocks of Malla Johar, *Palæont. Ind.*, ser. XV, Himâl Foss., Vol. I, Pt. I.

- Pinacoceras* sp. ind. aff. *rex*. Mojs.
Placites cf. *peractus* Mojs.
Discotropites cf. *sandlingensis* Hau.
Tropites cf. *subbullatus* Hau.
 " sp. ind. aff. *acutangulo* Mojs.
 " sp. ind. aff. *Wodani* Mojs.
Anatropites cf. *spinosus* Mojs.
 " *Pilgrinii* Dien.
Margarites *irregularicostatus* Dien.
Jovites cf. *spectabilis* Dien.
 " *daciformis* Dien.
Juvavites *Krafftii* Dien.
 " *dogranus* Dien.
 " nov. sp. ind. aff. *subinterrupto* Mojs.
Griesbachites *pseudomedleyanus* Dien.
 " cf. *Kastneri* Mojs.
Anatomites sp. ind. aff. *Camilli* Mojs.
 " " " " *Henrici* Mojs.
 " " " " *crasseplicato* Mojs.
Gonionotites cf. *italicus* Gemm.
Tibetites *bhotensis* Dien.
Loxonema (*Polygirina*) cf. *elegans* Hoern.
Sagana cf. *geometrica* Kok.
Capulus (*Phryx*) *joharensis* Dien.
Naticopsis sp. ind. aff. *obvallatæ* Kok.

This fauna has intimate relations both with the julic (middle carnic) and tuvalic (upper carnic) faunæ of the Alpine Hallstatt limestone. There is an assemblage of species indicating nearly equal affinities with the zones of *Trachyceras aonoides* and of *Tropites subbullatus*. The red marble of the exotic block No. 2 must therefore be considered as a homotaxial equivalent of both the middle and upper carnic substages.

The carnic stage, as represented in the exotic blocks Nos. 2 and 5, exhibits very important lithological differences from the dark shales and limestones of the beds with *Halobia comata* or the Grey beds and *Tropites* shales of the main region of the Himalayas. On the other hand, its lithological resemblance to the carnic Hallstatt limestone of the Roethelstein near Aussee is so great that it is no easy matter to distinguish rock specimens or fossils from those two localities without a close

inspection. The agreement with the Alpine Hallstatt limestone is lithological as well as faunistic. The faunistic difference between the carnic beds of the Himálayan and Tibetan facies, which are not more than a few miles apart, is much more conspicuous than between the latter and the Hallstatt limestone of the Roethelstein.

Fifteen species are identical, or probably identical, with Alpine forms and nineteen altogether with forms which have their habitat in the Mediterranean province, including four species, which are known to us from Sicily but not from the Eastern Alps. This is an unusually large percentage of Mediterranean types in an Indian fauna, and is only exceeded by the Mediterranean affinities of the Lower Liassic fauna of the exotic blocks Nos. 16 and 17 south of the Kiogarh high plateau.

Particularly striking is the preponderance of the genera *Arcestes* and *Cladiscites* in number of individuals in the Tibetan facies, whereas those two genera are of rare occurrence in the carnic stage of the main Triassic region of the Himálayas. In this character the carnic fauna of the Tibetan facies agrees exactly with that of the Alpine Hallstatt limestone.

e. Dachsteinkalk.

To the east of Chitichun No. I an exotic block was noticed by Diener (*Ergebnisse*, etc., i. c., p. 602), which is remarkable on account of its regular conical shape. It is built up of a yellowish-grey limestone, recalling the higher beds of the Upper Triassic Dachsteinkalk of the Shalshal cliff section.

In the region of exotic blocks of Malla Johar the divide between Kiogarh No. I and No. V has been described by A. v. Krafft as consisting of a great mass of grey, dolomitic limestone, without any fossils, but resembling the upper noric or rhætic Dachsteinkalk of the main region. "Nevertheless there is no complete lithological identity between the two, the Tibetan grey limestone being massive throughout, while the Himálayan Dachsteinkalk is well bedded."¹

f. Summary.

All Triassic beds represented in the exotic blocks of the Chitichun region and of Malla Johar belong to a facies different from that of the

¹ A. v. Krafft, Exotic blocks of Malla Johar, l. c., p. 147.

corresponding deposits in the Himálayan region. Those which are equivalent to the Dachsteinkalk of the Himálayan series are developed in a facies of white, dolomitic limestone. Their thickness and horizontal distribution is considerable, but the complete absence of fossils lessens their interest.

All the remaining exotic blocks agree in their mode of development with the red limestones and marbles of the Hallstatt facies in the Alpine region. Those of Lower Triassic and Muschelkalk age exhibit close faunistic affinities with the corresponding beds of the Himálayan facies from which they differ only lithologically. But in the carnic stage there is both a faunistic and lithological contrast with the Himálayan series, and a very close affinity with the middle and upper carnic fauna of the Mediterranean zoo-geographical province.

Among the liassic fossils of the Tibetan facies the Mediterranean affinities are marked still more strongly than in the Trias, the difference between the liassic faunæ of England or Wurtemberg and those of the Alps being even more conspicuous than between the latter and the lower liassic ammonites of the Tibetan facies found in the exotic blocks.

If no other Mesozoic faunæ in the Himálayas were known than those of the carnic stage from the exotic block No. 2, and of the Lower Lias from the blocks Nos. 16 and 17, their knowledge would not justify the establishment of an Indian zoo-geographical province.

Whereas an independent development of the Mesozoic faunæ is noticed in the Eastern basin of the Tethys, which corresponds to the main belt of the Himálayas compared with the development in the Mediterranean region, the contrast between them is almost obliterated in the area of the Tibetan facies. To the north of the main belt of the Himálayas sediments were deposited of a nearly uniform lithological character, agreeing with the Hallstatt facies of the Mediterranean province, and the sea was inhabited by a fauna with insignificant local peculiarities during carnic and liassic times.

This striking lithological and faunistic agreement, which exists between a considerable part of the Mesozoic sediments of the Tibetan facies and the homotaxial beds of the Mediterranean region, is one of the most interesting facts in Himálayan stratigraphy. It cannot be explained satisfactorily by the hypothesis that the exotic blocks in Malla Johar are not found *in situ* but have been carried there from a territory lying much further to the north. This hypothesis which has

been offered by Suess and in a somewhat altered form by A. v. Krafft, but which is not supported by convincing reasons, is only able to explain the rapid change of facies between the Tibetan and Himálayan series, but leaves the agreement of the Tibetan and Alpine series during the carnic and liassic periods unexplained.

IV.—THE CEPHALOPOD HORIZONS OF THE HIMALAYAN TRIAS.

The Trias of the Himálayas has been termed a cephalopod-bearing facies by several authors. But this statement can be made only with great reserve. It is true that some horizons are, indeed, conspicuous by an abundance of *Cephalopoda*, which is not surpassed by any in the Alps. But those horizons are, as a rule, of small thickness and separated by mighty masses of rocks very poor in fossils.

The cephalopod-bearing beds come to a close rather abruptly in the lower noric stage. In the higher divisions of this stage ammonites are of the rarest occurrence, and in the Indian equivalents of the Alpine Dachsteinkalk they are wanting altogether. From their fossils the enormous mass of shales, sandstones, quartzites, dolomites and limestones, which follow above the Juvavites beds of Spiti or above the Halorites limestone in Painkhanda, might be determined as a brachiopod or a bivalve facies, but certainly not as a cephalopod facies. Even in the Tibetan region of exotic blocks, where the faunæ of the Lower and Middle Triassic, carnic and liassic beds are represented almost exclusively by cephalopods, the grey limestones of the noric or rhætic stages are practically unfossiliferous. They have not yet yielded any ammonites.

It is necessary to state this, in order to prevent the student of the Himálayan Trias from forming exaggerated ideas on the abundance of cephalopod-bearing horizons. Those horizons are undoubtedly of the highest stratigraphical and faunistic importance, but are of small thickness in comparison with the unfossiliferous rocks, especially so in the Upper Trias.

In the Himálayan Trias ten cephalopod-bearing horizons have been distinguished by Noetling (*Asiatische Trias*, l.c., p. 177), who correlated the *Otoceras* beds with the Permian system.

The following table shows the distribution of cephalopod horizons in Spiti (sections near Lilang), Painkhanda (Bambanag and Shalshal cliffs), Byans and Malla Johar. It is from a combination of our experiences in those four areas, that we shall arrive at establishing a general standard of cephalopod-bearing horizons in the Central Himálayas.

It must, however, be remarked, that among those fifteen Triassic cephalopod horizons the existence of three is rather doubtful. No. 5 perhaps does not correspond to an independent palæontological zone, as defined by a peculiar fauna of ammonites, although *Rhynchonella Griesbachi* is restricted to this horizon. From No. 9 only a single ammonite, *Joannites thanamensis* Dien., is known. No. 15 has been based on two fragmentary specimens of ammonites, collected from the Monotis beds in Spiti and from the main layer of *Anodontophora Griesbachi* in Painkhanda. In neither case have I been able to determine the species.

	Spiti.	Painkhanda.	Byans.	Exotic blocks of Chitichun and Malla Johar.
Noric stage .	<p>15. Horizon of <i>Trachypleuraspides</i> aff. <i>Griffithi</i>.</p> <p>14. Horizon of <i>Juvavites angulatus</i>.</p>	<p>15. Horizon of <i>Sagenites</i> sp. ind.</p> <p>14. Horizon of <i>Halorites procyon</i>.</p> <p>13. Horizon of <i>Proclydonautilus Griesbachi</i>.</p>	<p>14. } Horizon of <i>Tro-</i> <i>pites</i> <i>subbul-</i> <i>latus</i> and <i>Halor-</i> <i>ites</i> sp. aff. <i>pro-</i> <i>cyon</i>.</p> <p>13. }</p>	
Carnic stage .	<p>12. Horizon of <i>Tropites subbullatus</i>.</p> <p>10. Horizon of <i>Joannites cymbiformis</i>.</p> <p>9. Horizon of <i>Joannites thanamensis</i>.</p>	<p>12. Horizon of <i>Mojssarites eugyrus</i>.</p> <p>11. Horizon of <i>Juvavites tonkinensis</i> and <i>Hypocladiscites subaratus</i>.</p> <p>10. Horizon of <i>Joannites cymbiformis</i>.</p>	<p>12. }</p>	<p>12. } Horizon of <i>Cladiscites</i> <i>crasse</i> <i>striatus</i>.</p> <p>11. }</p>

	Spiti.	Painkhanda.	Byans.	Exotic blocks of Chitichun and Malla Johar.
Ladinic stage	8. Horizon of <i>Protrachyceras Archelaus</i> .			
Muschelkalk	7. Horizon of <i>Cerattites Thuillieri</i> and <i>Ptychites rugifer</i> . 6. Horizon of <i>Keyserlingites Dieneri</i>	7. Horizon of <i>Cerattites Thuillieri</i> and <i>Ptychites rugifer</i> . 6. Horizon of <i>Keyserlingites Dieneri</i> . 5. Horizon of <i>Sibirites Prahlada</i> .	7. Horizon of <i>Cerattites Thuillieri</i> .	6. Horizon of <i>Monophyllites Confucii</i> .
Lower Trias	3. Horizon of <i>Hedenstræmia Mojsisovicsi</i> and <i>Flemingites Rohilla</i> . 2. Horizon of <i>Meekoceras Varaha</i> . 1. Horizon of <i>Otoceras Woodwardi</i> .	3. Horizon of <i>Hedenstræmia Mojsisovicsi</i> and <i>Flem. Rohilla</i> . 2. Horizon of <i>Meekoceras Markhami</i> . 1. Horizon of <i>Otoceras Woodwardi</i> .	4. Horizon of <i>Sibirites spiniger</i> . 3. Horizon of <i>Hedenstræmia Mojsisovicsi</i> .	3. Horizon of <i>Meekoceras joharensis</i> .
Permian	Horizon of <i>Cyclolobus insignis</i> .			

Four cephalopod horizons are known to us from the Lower Trias, two or perhaps even three from the Muschelkalk, one from the ladinic, three (or four ?) from the carnic, two (or three ?) from the noric stage. In comparing the number of cephalopod horizons with the thickness of the corresponding rock-groups, it is evident at once that the Himálayan Lower Trias and Muschelkalk deserve indeed the name of cephalopod facies, whereas this is not the case in the Upper Trias. In the carnic and noric beds of Spiti we may pass through many hundred feet of shales and limestones, without meeting with a single cephalopod-bearing layer.

A correlation of the Triassic cephalopod horizons of the Himálayas and of the Eastern Alps is illustrated in the following table :—

	Eastern Alps.	Himálayas.
Rhætic .	Horizon of <i>Choristoceras Marshi</i> .	
Noric stage .	Horizon of <i>Sirenites Argonautæ</i> . " „ <i>Pinacoceras Metternichii</i> . " „ <i>Cyrtopleurites bicrenatus</i> . " „ <i>Cladiscites ruber</i> . " „ <i>Sagenites Giebeli</i> .	Horizon of <i>Halorites procyon</i> . " „ <i>Proclydonautilus Griesbachi</i> .
Carnic stage .	Horizon of <i>Tropites subbullatus</i> . " „ <i>T. Aonoides</i> . " „ <i>T. Aon</i> .	Horizon of <i>Tropites subbullatus</i> . " „ <i>Hypocladiscites subaratus</i> . " „ <i>Joannites cymbiformis</i> . " „ <i>Joannites thanamensis</i> (P).
Ladinic stage	Horizon of <i>Protrachyceras Archelaus</i> . " „ <i>Dinariites avisianus</i> . " „ <i>Protrachyceras Curionii</i> .	Horizon of <i>Protrachyceras Archelaus</i> .
Muschelkalk .	Horizon of <i>Ceratites trinodosus</i> . " „ <i>Ceratites binodosus</i> .	Horizon of <i>Ceratites Thuillieri</i> . " „ <i>Keyserlingites Dieneri</i> . " „ <i>Sibirites Prahlada</i> .
Lower Trias .	Horizon of <i>Tirolites cassianus</i>	Horizon of <i>Sibirites spiniger</i> . " „ <i>Hedenstræmia Mojsisovicsi</i> . " „ <i>Meekoceras Markhami</i> . " „ <i>Otoceras Woodwardi</i> .
Permian .	Horizon of <i>Paralecanites sextensis</i> .	Horizon of <i>Cyclolobus insignis</i> .

It becomes clear from this table that the number of cephalopod-bearing horizons in the Himálayas is considerably larger in the Lower Trias than in the Alps, but smaller in the ladinic and noric stages. The absence of cephalopod horizons in the alaunic and sevatic (middle and upper noric) substages of the Himálayas is easily explained by the different development of facies in the Indian and Alpine regions. In the Alps it is only in the Hallstatt facies of the Salzkammergut that cephalopod facies are known, not in the *Lithothamnium* and bivalve facies of the Dachsteinkalk. But in rocks of the Hallstatt facies, as they are known to us from the Tibetan facies in the Himálayas, only the carnic stage is represented. The expectation may, however, be indulged in that in the Tibetan region further investigations may lead to the discovery of exotic blocks with middle and upper noric faunæ.

The presence of a single cephalopod fauna in the ladinic stage of the Himálayas is more remarkable. In the Alps three faunæ have been distinguished in this stage by E. v. Mojsisovics, two of them (Buchenstein and Wengen) being quite distinct and restricted to two stratigraphical horizons of wide distribution. In the Himálayas one fauna only corresponds to those three Mediterranean ones and this is the fauna of the Wengen beds with *Protrachyceras*, *Archelaus* and *Daonella Lommeli*. But there is certainly no break in the succession of beds, either in Spiti where the ladinic stage is at least 300 feet in thickness, or in Painkhanda where it is reduced to a thickness of 10 or 20 feet. In all the sections that have been examined by A. v. Krafft, true passage beds have been noticed connecting the upper Muschelkalk with the ladinic stage. From this we must infer that the topmost beds of the upper Muschelkalk, containing *Ptychites Gerardi* Blfd. and *Joannites cf. proavus* Dien., represent also stratigraphical equivalents of the Alpine Buchenstein beds the existence of which cannot be proved on palæontological grounds.

The following table shows a correlation of the Triassic cephalopod horizons of the Himálayas and of the Boreal and Pacific regions. Our limited knowledge of the Trias in the Arctic regions and in the southern part of the Pacific is a serious obstacle to any attempt of this kind:—

	Himálayas.	Boreal region.	Western Pacific Province.	California and Idaho.
Norie	Hor. of <i>Halorites procyon</i> . " " <i>Prochydontius Griesbachi</i>.	...	Hor. of <i>Astroconites saviticus</i> (Sav.). Cephalopod horizon of New Caledonia.	Hor. of <i>Halorites americanus</i> and <i>Rhabdoceras Russellii</i> .
Carnie	Hor. of <i>Tropites subballatus</i> . " " <i>Hypocladiscites subaratus</i> . " " <i>Joannites cymbiformis</i> . " " <i>Joannites thanamensis</i> .	Hor. of <i>Clionites Barrentsi</i> (Bears Island). Cephalopod horizon of New Siberia. Hor. of <i>Protrachyceras Snegdrupi</i> (Eureka Sound).		Hor. of <i>Tropites subballatus</i> (Hosselkus limestone). Hor. of <i>Protrachyceras</i> cf. <i>Hemfrayi</i> .
Lalime	Hor. of <i>Protrachyceras Archelaus</i> .		Hor. of <i>Japonites Japonicus</i> (Rikaren).	
Muschelkalk	Hor. of <i>Ptychites yunifer</i> and <i>Ceratites Thuillieri</i> . " " <i>Keuserlingites Dieneri</i> . " " <i>Sibirites Prahladi</i> .	Hor. of <i>Ptychites trochleiformis</i> (Spitzbergen). " " <i>Ceratites Vega</i> (Spitzbergen).	" " <i>Monophyllites sikhoticus</i> (Ussuri).	Hor. of <i>Ceratites trindosus</i> . Hor. of <i>Parapopanoeceras Haugi</i> .
Lower Trias.	Hor. of <i>Sibirites spiriger</i> . " " <i>Hedenstromia Mojsisovicsi</i> . " " <i>Meekoceras Markhami</i> . " " <i>Otoceras Woodwardi</i> and <i>Ophiceras Sakuntala</i> .	Hor. of <i>Keuserlingites subrobustus</i> (Olenek). Hor. of <i>Diuanites Hirschschii</i> (Timor). Hor. of <i>Proptychites hienanensis</i> (Ussuri).		Hor. of <i>Columbites parisiensis</i> . Hor. of <i>Trochites</i> cf. <i>Haueri</i> . Hor. of <i>Meekoceras gracilistatis</i> .

It is evident from this table that the Triassic Cephalopod horizons of the Himálayas are more complete than in any part of the Pacific or Boreal regions. It is especially in the ladinic and noric stages that cephalopod-bearing beds are rare, being represented by bivalve faunæ and only very few ammonites in those two zoo-geographical provinces.

V.—THE INDIAN TRIASSIC PROVINCE.

It is generally accepted that in the region occupied by the Himálayas, the Salt Range of the Punjab ; the Pamir, the frontier ranges of Yunnan, Burmah and Tonking there existed in the Mesozoic era a part of the ancient ocean, known as Tethys, the Triassic faunæ of which bear quite a distinct local character, which distinguishes them from the homotaxial faunæ of the Mediterranean and Pacific regions.

E. v. Mojsisovics¹ in 1896 pointed out the succession of the Indian Triassic cephalopod faunæ and the relation that the Indian province bears to the Mediterranean and Pacific provinces. As has been demonstrated in the preceding chapter, we are able now to construct a more complete and detailed account of the succession of cephalopod horizons, although the younger divisions of the noric stage are still wanting.

Now we can also move a considerable step further in the direction of defining more clearly the relation of the Indian to the Pacific region during the Triassic period. The points formerly obscure in our knowledge of the Trias of North America have been settled by the careful investigations of Hyatt and J. P. Smith, and very important new data respecting the Triassic deposits of New Caledonia have been published quite recently by Piroutet. The large gap between the Trias of the Himálayas and of the western Pacific region has been filled partly by the investigations of Leclere, Lantenois and Mansuy in Yunnan and Tonking and of Boehm, Hirschi, Voltz in the Sunda Islands.

The boundary between the Triassic deposits of the Indian and Mediterranean regions is very sharp. What is known of Triassic rocks in Asia Minor, in the Caucasus and in Darwaz, bears the stamp of the normal Mediterranean development. In Asia Minor the Triassic series

¹ E. v. Mojsisovics: Beiträge zur Kenntnis der obertriadischen Cephalopodenfaunen des Himálaya, *Denkschr. kais. Akad. d. Wiss. Wien*, LXIII, p. 686,—Himaláyan Fossils, I.c., Vol. II, pt. 2, p. 66.

is more complete than in any other district of Western Asia. Lower Trias is known from Gebse (gulf of Ismid) in the facies of Werfen beds. The fauna, which has been described by A. Bittner,¹ agrees exactly with that of the Alpine Buntsandstein. It is overlain by grey crinoid limestones and by grey and red limestones containing a rich fauna of the Muschelkalk. This fauna in which cephalopods predominate, has been assigned to the upper Muschelkalk (zone of *Ceratites trinodosus*) by Toulou,² to the lower Muschelkalk by G. v. Arthaber³ and Noetling.⁴ The presence of the ladinic stage is indicated by *Protrachyceras anatolicum* Toulou.

Upper Triassic deposits are known to us from Baalia Maaden (Mysia) by the investigations of G. v. Bukowski,⁵ who stated them to overlie unconformably beds of an Upper Carboniferous age. Their fauna was studied by Bittner.⁷ It contains both noric and rhætic⁶ elements, but exclusively *Brachiopoda*, *Lamellibranchiata* and *Gastropoda*. *Spirigera Manzavini* Bittn., *Mysidia* Bittn., *Pergamidia* Bittn., are the most remarkable types. There is no affinity whatever with the Upper Trias of the Himálayas.

In the Caucasus, sediments of the marine Trias were discovered at three different localities by W. J. Worobieff in 1906. The most complete section was observed on the slope of Mount Tchatch near the source of the river Sokhraia, a tributary of the Bielaia. According to the preliminary descriptions given by Th. Tschernyschew,⁹ who examined

¹ A. Bittner : *Neues Jahrb. f. Min.*, 1899, I, p. 66.

² F. Toulou : Eine Muschelkalkfauna am Golf von Ismid in Kleinasien, *Beiträge zur Geol. u. Palæont. Oesterr.-Ungarns etc.*, 1896, X, pp. 153-191.

³ G. v. Arthaber, *ibidem*, XII, p. 226.

⁴ F. Noetling, *Asiatische Trias*, I. c., p. 115.

⁵ F. Toulou : Ueber *Protrachyceras anatolicum*, ein neues Triasfossil vom Golfe von Ismid, *Neues Jahrb. f. Min.* etc., 1898, I, p. 26.

⁶ G. v. Bukowski : Die geologischen Verhältnisse der Umgebung von Baalia Maaden im nordwestl. Kleinasien. *Sitzgsber. Kais. Akad. d. Wiss. Wien.*, CI, 1892, p. 214.

⁷ A. Bittner : Triaspetrefakten von Baalia in Kleinasien, *Jahrb. K. K. Geol. Reichsanst.*, 1891, XLI, p. 97.—Neue Arten aus der Trias von Baalia, etc., *ibid.*, 1892, XLII, p. 77.

⁸ Bittner determined the age of this fauna as "rhætic," taking the rhætic stage in the wide circumscription of F. v. Hauer, who united in this stage all Triassic beds younger than carnic.

⁹ Th. Tschernyschew : Ueber die Entdeckung von oberer Trias im nördl. Kaukasus. *Bull. Acad. Imper. des sciences, St. Petersburg*, 1907, p. 277.

the rich materials of *Brachiopoda* and *Lamellibranchiata* collected by Worobieff, the Triassic series begins with shales containing *Koninckina Telleri* Bittn. and *Nucula strigillata* Goldf., which must be correlated with the carnic stage. They are overlaid by grey and red limestones, which have yielded a rich fauna of noric and rhætic age. The following are the most characteristic species:—

Pseudomonotis ochotica Keyserl.

Amphiclinodonta Katzeri Bittn.

„ *Suessii* Hofm.

Terebratula pyriformis Suess.

„ *turcica* Bittn.

Waldheimia reflexa Bittn.

Spiriferina Suessi Winkl.

„ cf. *kæssenensis* Zugm.

Spirigera Manzabini Bittn.

„ *oxykolpos* Emmr.

Retzia superbesecens Bittn.

Rhynchonella fissicostata Suess.

„ *levantina* Bittn.

„ *Fuggeri* Bittn.

This fauna shows a decidedly Mediterranean character, with the sole exception of *Pseudomonotis ochotica*, which points to a connection of the Mediterranean with the Siberian region.¹ Most of the fossils are identical or closely allied with species from Baalia Maaden. There is no affinity with the Upper Triassic faunæ of the Himalayas.

Fossils of Lower Triassic age—*Pseudomonotis (Claraia) Clarai* and *Tirolites* sp.—were noticed from Djulfa (Armenia) by E. v. Mojsisovics.² They occur in a quartzite series, which follows above grey marls and limestones containing *Lima Footei* Waag. Their stratigraphical position is considerably higher than that of the Permian *Otoceras* beds of Djulfa, but F. Frech and G. v. Arthaber³ have not succeeded in fixing it exactly in Abich's section across the Araxes

¹ *Pseudomonotis ochotica* is also known from the Upper Triassic shales and sandstones of Simferopol in the Crimea (G. v. Arthaber, *Alpine Trias, Lethæa mesoz.*, Bd. I, p. 440).

² E. v. Mojsisovics: Zur Altersbestimmung der Sedimentformationen in der Araxesenge bei Djulfa in Armenien, *Verhandl. K. K. Geol. Reichsanst.*, 1879, p. 171.

³ F. Frech and G. v. Arthaber: Ueber das Palæozoikum in Hocharmenien und Persen, *Beiträge zur Geol. u. Pal. Oesterr. Ungarns etc.*, XII, 1900, p. 176.

valley. The presence of *Tirolites* is indicative of the Mediterranean facies of the Lower Trias in Armenia.

Typical Werfen beds were discovered in Darwaz near Raman not far from the Afghan frontier by A. v. Krafft.¹ They consist of red sandstone, grey limestone, red and grey clay of enormous thickness (800 to 1,000 m.). Both the sandstone and limestone are rich in gastropods and bivalves. Ten species were determined by Bittner,² all of them characteristic elements of the Alpine Werfen beds. Thus the faunistic and lithological agreement is equally close.

The difference between the Lower Trias of the Himálayas and of the Salt Range on the one hand, and of Darwaz on the other is very sharp, but not sharper than that between the Himálayan and Tibetan facies of the Indian Trias.

The presence of Triassic sediments in Oman near Elphinstone inlet, is still rather doubtful, although *Myophoria omanica* Dien., which is nearly allied to the Alpine *M. inaequicostata* Klipst., indicates a Triassic age for some of the rocks.³

During the Middle and Upper Triassic periods Afghanistan was the western branch of the Indian zoo-geographical region.

The fauna of the shales and sandstones of the Kara Koh in the province of Herat, which were discovered by C. L. Griesbach in 1886,⁴ is unfortunately known too little to fix its age with any certainty. The presence of coal measures, of *Daonella Lommeli* and of *Monotis salinaria*, two bivalves standing widely apart in the stratigraphical scale of the Alpine Trias, has been recorded by Griesbach, but the cursory field-determinations of these fossils have not been confirmed by any subsequent examination.⁵

The association of marine strata rich in *Daonella*, with terrestrial plant-bearing beds reminds us strongly of the development of the Upper Trias in Sumatra, as has been stated by Noetling.

¹ A. v. Krafft : Geologische Ergebnisse einer Reise durch das Chanat Bokhara, *Denkschr. Kais. Akad. d. Wissensch.*, Wein, LXX, 1901, pp. 49-72.

² A. Bittner : *Jahrb. K. K. Geol. Reichsanst.*, 1898, 48 Bd., pp. 689-718.

³ C. Diener, Note on some fossils from the sedimentary rocks of Oman (Arabia).—*Records, Geol. Surv. of India*, Vol. XXXVI, 1908, p. 156.

⁴ C. L. Griesbach : Field notes, etc. *Records, Geol. Surv. of India*, 1886, Vol. XIX, pp. 235-267.

⁵ Recent work in Afghanistan has thrown considerable doubt on the accuracy of these determinations (*Mem., Geol. Surv. India*, Vol. XXXIX, p. 31).—Ed.

A large development of Upper Triassic rocks was disclosed in the highlands of the Pishin district (Baluchistan) by E. Vredenburg in 1901.¹ *Monotis salinaria* Schloth. and *Halorites* *sp. ind. aff. subcatenato* Mojs. point to a noric age. The shales including those species are probably homotaxial with the *Monotis* beds of Spiti and certainly not older than the middle noric (alaunic) substage.

From the Himálayas of Nepal our knowledge of Triassic fossils is limited to a valve of *Halobia* comparable to *H. Charleyana* Mojs. and to the cast of a *Ptychites* belonging to the section *rugiferi*, both of them represented in Wallich's collections from Muktinath, on the upper part of the river Kali or Buria Gandak, and south of Lob Mantang. A description of those scanty materials has been given recently by F. R. Cowper Reed.²

In Tonking the presence of the carnic stage has been established by Diener, who discovered *Juvavites tonkinensis* Dien., one of the species of the julic beds with *Halobia comata* in the Bambanag section, among the materials brought from the source of the Red river by French officers.³ A wide distribution of Triassic rocks has been recorded recently by Zeil, Lantenois, Camillon, Mansuy,⁴ in the environs of Lang-son and Binn-Lieuh. The fossils, which have been described by H. Mansuy,⁵ indicate the presence of Lower, Middle and Upper Triassic horizons.

The Trias of Tonking consists of shales, sandstones and limestones, which have been folded very strongly. *Xenodiscus cf. lissarensis* Dien. and *Pseudomonotis Griesbachii* Bittn. are referable to the Lower Trias, perhaps to its lowest stage, the *Otoceras* beds. The occurrence of *Inyoites cf. Oweni* Hyatt et Smith and of an ammonite, which has

¹ E. Vredenburg : On the occurrence of a species of *Halorites* in the Trias of Baluchistan. *Records, Geol. Surv. of India*, 1904, Vol. XXXI, p. 162.—C. Diener : Notes on an Upper Triassic fauna from the Pishin district, Baluchistan, *ibidem*, 1906, XXXIV, p. 12.

² F. R. Cowper Reed : Fossils from Nepal, *Geol. Magazine*, Dec. V, New ser., Vol. V, 1908, p. 261.

³ C. Diener : Note sur deux espèces d' Ammonites triassiques du Tonkin, *Bull. Soc. Geol. de France*, 3 ser., T. XXIV, p. 882.

⁴ G. Zeil, H. Lantenois, R. de Lamothe : Contribution à l'étude géologique de l'Indochine, *Mém. Soc. Geol.*, IV ser., T. I., 1907, Mem. No. 4, p. 24.

⁵ H. Mansuy : Contribution géologique à la carte de l'Indochine, *Paléontologie*, Hanoi 1908, pp. 62-73.

been compared to *Columbites* by Mansuy, points to a close faunistic affinity with the Lower Trias of Idaho and California. The determination of *Norites*, which was quoted by Douvillé¹ in 1896, is rather doubtful.

The presence of Muschelkalk is very uncertain. It might be inferred from a badly preserved specimen of *Ceratites*, recalling *C. Airavata* Dien.

The fauna of the carnic stage is represented by the following species :—

Lima cf. subpunctata D'Orb.

Pecten cf. tubulifer Muenst.

Hoferia cf. auplicata Muenst.

Hærniesia cf. Joannis Austriæ Klipst.

Palæoneilo cf. Faba Wism.

Myophoria cf. inaequicostata Klipst.

„ *Goldfussi* Alb.

The noric stage is indicated by *Clionites cf. Salteri* Mojs., by some fragments of ammonites, which have been compared to *Paratibetites* Mojs. by Mansuy, by a species of *Spiriferina*, which is perhaps nearly allied to *Sp. Griesbachi* Bittn., and by a cast of a bivalve resembling *Anodontophora Griesbachi* Bittn.

The development of the carnic stage in the vicinity of Lang-son differs considerably from that in the Himálayas. It exhibits a closer affinity with the homotaxial Triassic beds in south-eastern China, as represented by the faunæ of Chungtien (Loczy)², Kwechou (Koken)³ and A-mi-chu (Mansuy).

The Triassic fauna discovered by L. von Loczy north of the great Buddhist temple of Chungtien in the valley of the Kingcha-Kiang, is imbedded in argillaceous shales, marls and sandstones. Its affinity with the German Muschelkalk has been overestimated. *Myophoria elegans* Dunk. is the only identical species. All the remaining forms point to a ladinic or carnic age, especially to the fauna of St. Cassian. This is also the age of the fauna of Kwei-chou, according to Koken.

¹ H. Douvillé, *Bull. Soc. Géol. de France*, 3 sér. I, XXIV, p. 454.

² Die wissenschaftlichen Ergebnisse der Reise des Grafen Béla Széchényi in Ostasien 1877-1880. Wien 1893, I, p. 738 III, p. 208.

³ E. Koken: Über triadsche Bersteinerungen aus China, *Neues Jahrb. f. Min.* etc., 1900, I, pp. 186-215.

⁴ Résultats de la mission géologique et minière du Yunnan Méridional Sept. 1903-Janvier 1904, *Annales des Mines*, 1907, pp. 71, 172.

The two faunæ are composed almost exclusively of *Brachiopoda*, *Gastropoda* and *Lamellibranchiata*, but have not yielded one single ammonite. A Himálayan fauna of this facies was discovered in the Grey beds of Spiti by H. Hayden and A. v. Krafft, but is certainly of younger age. The scientific mission to southern China in 1898 under command of M. Leclère discovered the beds with *Myophoria Szechengi* Loczy near Sui-Longtien. By the expedition to Yunnan in 1903 the presence of two Upper Triassic horizons has been recorded near A-mi-chu and Yen-fen-chwang. The lower horizon corresponds to the bed with *Myophoria Szechengi*, which in this section is associated with *Daonolla indica* Bittn. This association is a strong argument in favour of a ladinic or lower carnic age of the fauna of Chungtien. The second horizon is the equivalent of the Raibl beds or zone of *Trachyceras aonoides*. It has yielded the following species of ammonites:—

Protrachyceras Thous Dittm.

Trachyceras Suessii Mojs.

Trachyceras austriacum var. *tibetica* Mojs.

In the district of A-mi-chu the Triassic fossils are imbedded in limestones, shales and variegated sandstones, which have been compressed into several sharp folds.

The northern borderland of the Indian Triassic province corresponds to the southern shore of the Angara continent (Suess). It must have been shifted considerably to the south since the close of the anthracolithic epoch. No rocks of Triassic age have as yet been found beyond the Semenow range near the boundary of North-eastern Tibet and the Chinese territory of Kansu.

The extension of the Indian marine Trias into the Malay Archipelago has been proved by the discovery of Triassic fossils in Wichmann's collections from the island of Rotti by Rothpletz.¹ But the researches of Voltz in Sumatra, Vogel in Borneo, Hirschi in Timor, G. Boehm in the islands of Serang, Savu and Misol, have carried the distribution of the distinctive faunæ of the carnic and noric stages still further to the east and west.

¹ A. Rothpletz: Die Perm Trias-und Juraformation auf Timor und Rotti im Malayischen Archipel. *Palæontographica*, Vol. XXXIX, p. 89.

Rotti is the classical locality in the Malay Archipelago, from which the first Triassic fossils were described in 1892 by Rothpletz. He distinguished a lower limestone and marl of carnic and a younger reddish-yellow limestone of noric age. This classification has been proved to be entirely correct, although a revision of the fossils by Renz¹ and Wanner² has led to some alterations in the determination of the species.

The leading fossils of the lower or carnic horizon are *Daonella Wichmanni* Rothpl. and *D. styriaca* Mojs. In the upper or noric horizon *Pseudomonotis ochotica* var. *densistriata* Tell. predominates. *Halobia* cf. *Hoernesii* Mojs., *H. cf. norica* Mojs., *H. cf. lineata* Muenst. point also to a probably noric age, but have not been found associated with the casts of *Pseudomonotis ochotica*, according to Rothpletz.

In Sumatra W. Voltz³ has acquainted us with a rich development of the carnic stage near the source of the Kwalu river. The Triassic beds consist of a yellow clay, about 600 feet in thickness, which is overlaid conformably by a series of sandstones, the average thickness of which amounts to 1,600 feet. In the sandstones thin bands of grey clay are intercalated irregularly. They contain casts of bivalves and numerous plant remains. This development has been compared with the coal-bearing Trias in the Afghan province of Herat by F. Noetling.

The yellow shaly clay at the base of the Kwalu sandstone has yielded *Daonella styriaca* Mojs. and *D. cassiana* Mojs. From the grey clay intercalated with the sandstone one species of *Daonella* and four of *Halobia* have been quoted by Voltz. All of them are new species, with the exception of a *Halobia*, which is probably identical with the Alpine *H. Charlyana* Mojs. From this fauna the carnic age of the entire series is evident.

From Kendai, in south-eastern Borneo, crumbling shales, rich in casts of *Monotis salinaria* Schloth., have been quoted by F. Vogel.⁴

¹ C. Renz: Timor und Rotti in Noetling, *Asiatische Trias*, I. c., p. 211, — Ueber *Halobia* und *Daonella* aus Griechenland nebst asiatischen Vergleichstuecken, *Neues Jahrb. f. Min. etc.*, 1906, I, p. 37.

² T. Wanner: Triaspetrefakten der Molukken und des Timorarchipels, in G. Boehm, *Geologische Mitteilungen aus dem Indo-austral. Archipel*, *Neues Jahrb. f. Min. etc.*, Beilagebd. XXIV, 1907.

³ W. Voltz: Beiträge zur geol. Kenntniss von Nord Sumatra, *Zeitschr. Deutsch. Geol. Ges.*, LI, pp. 1-61.

⁴ F. Vogel: Beiträge zur Kenntnis der mesozoischen Formationen in Borneo, *Sammlgn. d. Geol. Reichsmuseums in Leiden*, ser. I, Bd. VII, 1902, p. 217.

It is impossible to decide whether or not this determination was correct since both *Pseudomonotis ochotica* and *Monotis salinaria* have been proved to occur in the Upper Triassic rocks of the Malay Archipelago.

Our knowledge of the Trias of Misol and Savu is very limited. Among the collections gathered from those islands by G. Boehm, *Daonella lilintana* from the shales of Lilinta (Misol) is identical with a species from the carnic beds of Sumatra. In the island of Savu the presence of Upper Triassic beds has been proved by the discovery of *Astroconites savuticus* Boehm. According to the present state of our knowledge the genus *Astroconites* is restricted to the noric stage of the Alpine Trias.

In eastern Serang a rich development of marine shales, sandstones and limestones of noric age was discovered by J. Wanner in 1904. It has yielded the following species:—

Montlivaltia moluccana Wann.

Thecosmilia nov. sp. ex. aff. *clathratae* Emmer.

Pachypora intabulata Wann.

Halorella amphitoma Bronn.

„ *plicatifrons* Bittn.

„ *rectifrons* Bittn.

Monotis salinaria Schloth.

Amonotis Rothpletzi Wann.

Vanikoro serangensis Wann.

The facies of the noric beds in Serang recalls strongly the carnic Kwalu sandstone of Sumatra. In the sandstones of Serang which occasionally pass into pure quartzites, plant remains and coal seams are met with rather frequently.

The fossils collected in the Triassic areas of Timor by Verbeek and Hirschi¹ and described by Wanner, belong to at least three different Triassic horizons. *Dinarites (Liccaites) Hirschii* Wann., represents a type of this genus which in the Mediterranean Triassic province is characteristic of the upper Werfen beds. It would therefore point to a Lower Triassic age. *Koninckina alfurica* Wann., which is associated with indeterminable *Halobiae* of the *rugosa* group, from Bahabubu (Portuguese Timor), *Daonella indica* Bittn. and *D. cf. styriaca*, which have

¹ H. Hirschi: Zur Geographie und Geologie von Portugiesisch Timor, *Neues Jahrb. f. Min. etc.*, Beilagebd, XXIV, 1907, p. 460.

not been found *in situ*, must be assigned to the carnian stage. The same conclusion is arrived at with respect to *Halobia moluccana*, a species allied very nearly to *H. Charlyana* Mojs., from Meta Mano Ledo. A reddish-yellow limestone, agreeing lithologically with the *Pseudomonotis* bed of Rotti, has yielded a cast of *Pseudomonotis ochotica* var. *densistriata*. This limestone must consequently be considered to be of noric age.

The Upper Triassic faunæ of the Malay Archipelago are distinguished by their close relationship to Indian and Mediterranean forms. The Halorella limestone of Serang agrees entirely with the Halorella limestone of the Eastern Pamir. The true *Monotis salinaria*, so often incorrectly cited, occurs in the two rock groups. It is a type characteristic of the Tethys, both in the Mediterranean and Indian regions. It is replaced by the group of *Pseudomonotis ochotica* in the Siberian and Pacific regions. It is only in the noric stage of Rotti that we find this Pacific type, which otherwise seems to be excluded from the Indian Upper Trias.

Thus the Malay region appears to have formed a connecting link between the Indian and Pacific Provinces during the Upper Triassic period. A similar connecting link between the Alpine and Siberian development of the Upper Trias is indicated by the noric beds of the Crimea and of the Caucasus, where *Pseudomonotis ochotica* is associated with a large number of brachiopods of truly Mediterranean type.

In the south of the Himalayan Mesozoic belt the Triassic Tethys was bordered by the old continent of Gondwanaland, the counterpart of the Angara continent to the north. But south-east of the Malay Archipelago an uninterrupted open connection must have existed between the Indian and Pacific oceans of the Upper Trias. This is evident from the astonishing influence of Indian and even Mediterranean elements on the Triassic faunæ of New Caledonia.

According to the valuable data which have been obtained recently by Piroutet,¹ there can now be no doubt as to the fact that in the marine Trias of New Caledonia several horizons exist comprising equivalents of the noric, carnian and even ladinian stages.

Two facies may be distinguished among the Triassic beds of this

¹ M. Piroutet, Note sommaire sur le Trias de la Nouvelle Calédonie, *Bull., Soc. Geol. de France*, 4 ser. t. VIII, 1908, pp. 324-329.

island. The eastern facies is represented by graphitic argillaceous shales with *Pseudomonotis Richmondiana* Zittel, which must be considered as deposits of considerable depth. The deposits of the western facies have been formed near the ancient shore. They are much thicker and partly rich in fossils. Their entire thickness is about 3,000 metres. Three main divisions are distinguishable among them.

The lowest division, attaining a thickness of nearly 1,000 metres, consists of basal conglomerates, argillaceous sandstones and shales, in which a mighty series of trachytic tufa and breccia is intercalated. One single fragment of *Orthoceras* only has been found near the base. The stratigraphical position of this division, which some geologists have correlated with Upper Palæozoic beds, is consequently uncertain.

The middle division has been divided into seven horizons by Piroutet. It consists of shales, clay, grauwacke, andesitic tufa and breccia. The lowest horizon is a bed with *Halobia Zitteli* Lindstr. and *Halobia Kivaluana* Volz. The first species is one of the leading bivalves of the shales and Myophoria sandstones of Bears Island¹ and of the calcareous shales of the Eureka sound.² The second species has been quoted from the grey *Daonella* clay of Sumatra by Volz. Thus this horizon is probably of Carnian, not of Ladinian age, as has been suggested by Piroutet.

This lowest horizon is overlaid by a bed with *Mytilus problematicus* Zittel and with large species of *Spirigera* and *Spiriferina*.

Then follows a bed very rich in fossils, which represent rather conflicting characters. With several species of *Halobia* of typical Carnian habit numerous brachiopods are associated, all of them Mediterranean forms, but characteristic of different stratigraphical horizons of the Alpine Trias. *Spiriferina fragilis* Schloth., *Rhynchonella decurtata* var. *dalmatina* Bittn., var. *devota* Bittn. are indicative of the Muschelkalk, *Spiriferina Lipoldi* Bittn., *Spiriferina gregaria* Suess, *Retzia ladina* Bittn., *Retzia quadricosta* Muenst., *Spirigera contraplecta* Muenst., *Spirigera indistincta* Beyr., *Terebratula Oppeli* Lbe. of the St. Cassian and Raibl beds, *Halorella* sp., *Rhynchonella angulifrons* Bittn., *Rhynchonella salinaria* Bittn. even of the Noric Hallstatt limestone and Dachsteinkalk.

¹ J. Boehm: Ueber die obertriadische Fauna der Bäreninsel, *Konigl. Svenska Vetensk. Akad. Handl.*, Vol. XXXVII, No. 3, 1903, p. 30.

² E. Kittl: Die Triasfossilien vom Eurekastrand, *Report second Norwegian Arctic Expedition "Fram,"* No. 7, 1907, p. 14.

In the three following horizons very large species of *Spiriferina* and *Spirigera*, belonging chiefly to the group of *Sp. Wreyi* Zitt., predominate. From the uppermost of those three horizons all the ammonites hitherto known have been collected. Besides *Rhacophyllites cf. neojuvrensis* Quenst. and *Stenarcestes nov. sp. ind.* described by E. v. Mojsisovics (Ammonites triasiques de la Nouvelle Calédonie, *Compte Rendu Acad. des Sciences*, Paris, 18, Novembre 1895), several indeterminate species of *Arcestes* have been found by Piroutet, among them representatives of the groups of *intuslabiati*, *bicarinati*, *coloni*, *sublabiati*.

This cephalopod-bearing horizon is overlaid by a bed containing numerous bivalves, among them *Halobia austriaca* Mojs., *H. cf. Suessii* Mojs., *H. cf. celtica* Mojs., *H. cf. comata* Bittn. Those species point to the Carnic stage as decidedly as the ammonites of the preceding horizon to the Noric stage. In the topmost beds of this division an amalgamation of Carnic and Noric elements seems to exist, which recalls the two different faunæ—one with Carnic and the other with Noric affinities—in the Tropites limestone of Byans.

The highest division of the Trias in New Caledonia agrees with the middle one lithologically, if we except the occasional intercalation of calcareous sandstones, but is of very considerable thickness (about 1,800 metres). It has yielded *Halobia rarestriata* near its base and *Pseudomonotis Richmondiana* in the upper part of the series, together with plant remains. It is only in this horizon of undoubtedly Noric age, that the Alpine fauna is replaced entirely by an element characteristic of the Arctic-Pacific province.

The affinities of the Triassic faunæ of New Caledonia with the Indian and Mediterranean faunæ are so close, that the Trias of this island can scarcely put in a claim for being separated from the Indian Triassic province as a special faunistic district.

No more recent data are available respecting the Triassic deposits of New Zealand, which belong to the Noric stage. In South America the presence of the marine Trias has been denied altogether by Steinmann,¹ who examined the section of Utcubamba in Peru, where the fossils reported hitherto as Triassic had been collected. Those fossils, which had been assigned to the Upper Trias by E. v. Mojsisovics (*Pseudomonotis ochotica*, *Metasibirites*, *Helictites*) have their habitat in a bed

¹ G. Steinmann, Keine marine Trias in Suedamerika, *Centralblatt, f. Min., etc.*, 1909, p. 1.

stratigraphically younger than the lower lias with *Agassizeras globosum*. The results of the detailed palæontological investigation of the faunæ from the valley of Utcubamba must be awaited before our uncertainty about the exact position of the South American beds with *Pseudomonotis ochotica* can be removed.

We have become acquainted with a wide extent of the Indian Triassic fauna from the province of Herat to New Caledonia. Over this large area the successive faunæ were distributed uniformly and had the same vertical range. But although the sediments were once continuous, a tolerably complete and connected account of their succession can only be constructed for the Himálayan region. In this district we have an uninterrupted development of *Cephalopoda*, which enables us to decide the enigmatical question as to the habitat of some cryptogene types.

It has been shown that *Xenodiscus* ranges from Permian into Lower Triassic strata, undergoing several modifications, among which the most typical genera of Lower Triassic ammonites might be found. The most important phylum of Triassic ammonites has its root in the Indian genus *Xenodiscus* Waag., but *Xenodiscus*, *Xenaspis*, *Ophiceras*, *Meekoceras* are all so closely allied at the commencement of the Mesozoic era, that it is barely possible to point out a distinct ancestor to every Triassic genus within this stock of radicals.

Meekoceras itself is probably a descendant of *Ophiceras*, more particularly of the type with a narrow umbilicus, which is represented by *O. Sakuntala*. Another branch of the genus *Ophiceras* is *Flemingites*, an intermediate shape between the two genera, *Fl. prænuntius*, having been described by Frech. But with equal reason some other species of *Flemingites* might be referred to *Xenodiscus*, as is demonstrated by the remarkable agreement of *Flemingites radiatus* Waag. with *Xenodiscus plicatus* Waag.

An important branch of discoidal ammonites with adventitious lobes certainly originated from *Meekoceras*. *Hedenstræmia* is also connected with this genus most intimately by *Clypites* Waag. (group of *Hedenstræmia lilangensis* Kr.). Types specialized more strongly are *Aspenites* Hyatt and *Pseudosageceras* Dien., which is connected with *Hedenstræmia* by a fragmentary species from the Meekoceras beds of Spiti.

Proavites, *Proptychites*, *Beyrichites* are all probably descendants from *Meekoceras* which have retained the originally smooth shells. But

there is some probability of *Meekoceras* being also the root from which a large phylum of *Ammonia trachyostraca* originated. Forms of *Meekoceras* with a faintly developed ornamentation, which crosses the external part (*M. Hodgsoni* Dien.) belong to a genetic series leading to *Sibirites* in the upper division of the Lower Trias and to *Acrochrodiceras* in the Muschelkalk.

But the most important Indian family of Triassic *Trachyostraca*, the *Ceratitidæ*, probably originated from *Xenodiscus*. This is pretty certain at least for the group of *Ceratites circumplicati* (*Hollandites*). *Ceratites pumilio*, the oldest representative of the genus, agrees with typical species of *Hollandites* in the shape of its cross section and in the pattern of its sculpture, with *Xenodiscus* in the development of its sutures and in its comparatively wide umbilicus.

The restriction of *Tirolitidæ* to the Mediterranean province during the Scythian period, emphasized by E. v. Mojsisovics in 1896, has not been confirmed by later researches, but their sporadic appearance clearly proves them to have been immigrants from the Mediterranean region, not autochthonous elements, such as the *Meekoceratidæ* and *Xenodiscidæ*. *Dinarites* also became independently developed within the Mediterranean and Boreal provinces, but cannot be regarded as an ancestor of the Indian *Ceratitidæ*.

The Indian Lower Trias is entirely deficient in *Arcestoidea*, which make a sudden simultaneous appearance both in the Himálayan and Alpine Muschelkalk. The considerable temporary intermittence between *Joannites* and the Permian *Cyclolobus* makes a genetic connection between those two genera questionable.

A second stock of cryptogene types, the *Haloritidæ*, which were not known to E. v. Mojsisovics before the carnic stage have been discovered recently in the Muschelkalk, where *Smithoceras* is a peculiar representative of this family. This fact proves the *Haloritidæ* to be an endemic element of the Indian province. But the problem of the habitat of *Haloritidæ* during the ladinic and lower carnic periods still remains undecided.

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MEMOIR
OF
THE GEOLOGICAL SURVEY OF INDIA.

VOLUME XXXVI, PART I

THE GEOLOGY OF SPITI, WITH PARTS OF BASHAHR AND
RUPSHU. *By* H. H. HAYDEN, B.A., B.E., F.G.S., *Deputy
Superintendent, Geological Survey of India.*

Published by order of the Government of India.

CALCUTTA :

SOLD AT THE OFFICE OF THE GEOLOGICAL SURVEY,
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LONDON : MESSRS. KEGAN PAUL, TRENCH, TRÜBNER & CO.
BERLIN : MESSRS. FRIEDLANDER UND SOHN.

1904.

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Vol. X, 1877.

- Part 1.*—Annual report for 1876. Geological notes on the Great Indian Desert between Sind and Rajputana. On the occurrence of the cretaceous genus *Omphalia* near Nameho lake, Tibet, about 75 miles north of Lhasa. On *Estheria* in the Gondwana formation. Notices of new and other vertebrata from Indian tertiary and secondary rocks. Description of a new *Emydine* from the upper tertiaries of the Northern Punjab. Observations on under-ground temperature.
- Part 2.*—On the rocks of the Lower Godavari. On the 'Atgarh Sandstones' near Cuttack. On fossil floras in India. Notices of new or rare mammals from the Siwaliks. On the Arvali series in North-eastern Rajputana. Borings for coal in India. On the geology of India.
- Part 3.*—On the tertiary zone and underlying rocks in the North-west Punjab. On fossil floras in India. On the occurrence of erratics in the Potwar. On recent coal explorations in the Darjiling district. Limestones in the neighbourhood of Barakar. On some forms of blowing-machine used by the smiths of Upper Assam. Analyses of Raniganj coals.
- Part 4.*—On the Geology of the Mahanadi basin and its vicinity. On the diamonds, gold, and lead ores of the Sambalpur district. Note on 'Eryon Comp. Barrovensis,' McCoy, from the Sripermatur group near Madras. On fossil floras in India. The Blaini group and the 'Central Gneiss' in the Simla Himalayas. Remarks on some statements in Mr. Wynne's paper on the tertiaries of the North-west Punjab. Note on the genera *Choromeryx* and *Rhagatherium*.

Vol. XI, 1878.

- Part 1.*—Annual report for 1877. On the geology of the Upper Godavari basin, between the river Wardha and the Godavari, near the civil station of Sironcha. On the geology of Kashmir, Kishtwar, and Pangi. Notices of Siwalik mammals. The palæontological relations of the Gondwana system. On 'Remarks, &c., by Mr. Theobald upon erratics in the Punjab.'
- Part 2.*—On the Geology of Sind (second notice). On the origin of the Kumaun lakes. On a trip over the Milam Pass, Kumaun. The mud volcanoes of Ramri and Cheduba. On the mineral resources of Ramri, Cheduba, and the adjacent islands.

Part 3.—Note on the progress of the gold industry in Wynaad, Nilgiri district. Notes on the representatives of the Upper Gondwana series in Trichinopoly and Nellore-Kistna districts. Senarmontite from Sarawak.

Part 4.—On the geographical distribution of fossil organisms in India. Submerged forest on Bombay Island.

VOL. XII, 1879.

Part 1.—Annual report for 1878. Geology of Kashmir (third notice). Further notices of Siwalik mammalia. Notes on some Siwalik birds. Notes of a tour through Hangrang and Spiti. On a recent mud eruption in Ramri Island (Arakan). On Braunitz, with Rhodonite, from near Nagpur, Central Provinces. Palæontological notes from the Satpura coal-basin. Statistics of coal importations into India.

Part 2.—On the Mohpani coal-field. On Pyrolusite with Psilomelane occurring at Gosalpur, Jabalpur district. A geological reconnaissance from the Indus at Kushalgarh to the Kurram at Thal on the Afghan frontier. Further notes on the geology of the Upper Punjab.

Part 3.—On the geological features of the northern part of Madura district, the Pudukota State, and the southern parts of the Tanjore and Trichinopoly districts included within the limits of sheet 80 of the Indian Atlas. Rough notes on the cretaceous fossils from Trichinopoly district, collected in 1877-78. Notes on the genus *Sphenophyllum* and other Equisetaceæ, with reference to the Indian form *Trizygia Speciosa*, Royle (*Sphenophyllum Trizygia*, Ung.). On Mysorin and Atacamite from the Nellore district. On corundum from the Khasi Hills. On the Joga neighbourhood and old mines on the Nerubudda.

Part 4.—On the 'Attock Slates' and their probable geological position. On a marginal bone of an undescribed tortoise, from the Upper Siwaliks, near Nila, in the Potwar, Punjab. Sketch of the geology of North Arcot district. On the continuation of the road section from Murree to Abbottabad.

VOL. XIII, 1880.

Part 1.—Annual report for 1879. Additional notes on the geology of the Upper Godavari basin in the neighbourhood of Sironcha. Geology of Ladak and neighbouring districts, being fourth notice of geology of Kashmir and neighbouring territories. Teeth of fossil fishes from Ramri Island and the Punjab. Note on the fossil genera *Nöggerathia*, Stbg., *Nöggerathiopsis*, Fstm., and *Rhoptozamites*, Schmalh., in palæozoic and secondary rocks of Europe, Asia, and Australia. Notes on fossil plants from Kattywar, Shekh Budin, and Sirgulah. On volcanic foci of eruption in the Konkan.

Part 2.—Geological notes. Palæontological notes on the lower trias of the Himalayas. On the artesian wells at Pondicherry, and the possibility of finding such sources of water-supply at Madras.

Part 3.—The Kumaun lakes. On the discovery of a celt of palæolithic type in the Punjab, Palæontological notes from the Karharbari and South Rewah coal-fields. Further notes on the correlation of the Gondwana flora with other floras. Additional note on the artesian wells at Pondicherry. Salt in Rajputana. Record of gas and mud eruptions on the Arakan coast on 12th March 1879 and in June 1843.

Part 4.—On some pleistocene deposits of the Northern Punjab, and the evidence they afford of an extreme climate during a portion of that period. Useful minerals of the Arvali region. Further notes on the correlation of the Gondwana flora with that of the Australian coal-bearing system. Note on reh or alkali soils and saline well waters. The reils of Upper India. Note on the Naini Tal landslip, 18th September 1880.

VOL. XIV, 1881.

Part 1.—Annual report for 1880. Geology of part of Dardistan, Baltistan, and neighbouring districts, being fifth notice of the geology of Kashmir and neighbouring territories. Note on some Siwalik carnivora. The Siwalik group of the Sub-Himalayan region. On the South Rewah Gondwana basin. On the ferruginous beds associated with the basaltic rocks of north-eastern Ulster, in relation to Indian laterite. On some Rajmahal plants. Travelled blocks of the Punjab. Appendix to 'Palæontological notes on the lower trias of the Himalayas.' On some mammalian fossils from Perim Island, in the collection of the Bombay Branch of the Royal Asiatic Society.

Part 2.—The Nahan-Siwalik unconformity in the North-western Himalaya. On some Gondwana vertebrates. On the ossiferous beds of Hundes in Tibet. Notes on mining records, and the mining record office of Great Britain; and the Coal and Metalliferous Mines Acts of 1872 (England). On cobaltite and danaite from the Khetri mines, Rajputana; with some remarks on Jaipurite (Syeppoorite). On the occurrence of zinc ore (Smithsonite and Blende) with barytes, in the Karnul district, Madras. Notice of a mud eruption in the island of Cheduba.

Part 3.—Artesian borings in India. On oligoclase granite at Wangtu on the Sutlej, North-west Himalayas. On a fish-palate from the Siwaliks. Palæontological notes from the Hazaribagh and Lohardagga districts. Undescribed fossil carnivora from the Siwalik hills in the collection of the British Museum.

Part 4.—Remarks on the unification of geological nomenclature and cartography. On the geology of the Arvali region, central and eastern. On a specimen of native antimony obtained at Pulo Obin, near Singapore. On Turgite from the neighbourhood of Juggia-pett, Kistnah district, and on zinc carbonate from Karnul, Madras. Note on the section from Dalhousie to Pangi, *via* the Sach Pass. On the South Rewah Gondwana basin. Submerged forest on Bombay Island.

VOL. XV, 1882.

Part 1.—Annual report for 1881. Geology of North-west Kashmir and Khagan (being sixth notice of geology of Kashmir and neighbouring territories). On some Gondwana labyrinthodonts. On some Siwalik and Jamna mammals. The geology of Dalhousie, North-west Himalaya. On remains of palm leaves from the (tertiary) Murree and Kasauli beds in India. On Iridosmine from the Noa-Dibing river, Upper Assam, and on Platinum from Chutia Nagpur. On (1) a copper mine lately opened near Yongri hill, in the Darjiling district; (2) arsenical pyrites in the same neighbourhood; (3) kaolin at Darjiling (being 3rd appendix to a report on the geology and mineral resources of the Darjiling district and the Western Duars). Analyses of coal and fire-clay from the Makum coal-field, Upper Assam. Experiments on the coal of Pind Dadun Khan, Salt-range, with reference to the production of gas, made April 29th, 1881. Report on the proceedings and result of the International Geological Congress of Bologna.

Part 2.—General sketch of the geology of the Travancore State. The Warkilli beds and reported associated deposits at Quilon, in Travancore. Note on some Siwalik and Narbada fossils. On the Coal-bearing rocks of the valleys of the Upper Rer and the Mand rivers in Western Chutia Nagpur. On the Pench river coal-field in Chhindwara district, Central Provinces. On borings for coal at Engsein, British Burma. On sapphires recently discovered in the North-west Himalaya. Notice of a recent eruption from one of the mud volcanoes in Cheduba.

Part 3.—Note on the coal of Mach (Much) in the Bolan Pass, and of Sharag or Sharigh on the Harnai route between Sibi and Quetta. New faces observed on crystals of stilbite from the Western Ghâts, Bombay. On the traps of Darang and Mandi in the North-western Himalayas. Further note on the connexion between the Hazara and the Kashmir series. On the Umaria coal-field (South Rewah Gondwana basin). The Daranggiri coal-field, Garo Hills, Assam. On the outcrops of coal in the Myanounng division of the Henzada district.

Part 4.—On a traverse across some gold-fields of Mysore. Record of borings for coal at Beddadanol, Godavari district, in 1874. Note on the supposed occurrence of coal on the Kistna.

VOL. XVI, 1883.

Part 1.—Annual report for 1882. On the genus *Richthofenia*, Kays (*Anomia Lawrenciana*, Koninck). On the geology of South Travancore. On the geology of Chamba. On the basalts of Bombay.

Part 2.—Synopsis of the fossil vertebrata of India. On the Bijori Labyrinthodont. On a skull of *Hippotherium antilopinum*. On the iron ores, and subsidiary materials for the manufacture of iron, in the north-eastern part of the Jabalpur district. On laterite and other manganese ore occurring at Gosulpore, Jabalpur district. Further notes on the Umaria coal-field.

Part 3.—On the microscopic structure of some Dalhousie rocks. On the lavas of Aden. On the probable occurrence of Siwalik strata in China and Japan. On the occurrence of *Mastodon angustidens* in India. On a traverse between Almora and Mussooree made in October 1882. On the cretaceous coal-measures at Borsora, in the Khasia Hills, near Laour, in Sylhet.

Part 4.—Palæontological notes from the Daltonganj and Hutar coal-fields in Chota Nagpur. On the altered basalts of the Dalhousie region in the North-western Himalayas. On the microscopic structure of some Sub-Himalayan rocks of tertiary age. On the geology of Jaunsar and the Lower Himalayas. On a traverse through the Eastern Khasia, Jaintia, and North Cachar Hills. On native lead from Maulmain and chromite from the Andaman Islands. Notice of a fiery eruption from one of the mud volcanoes of Cheduba Island, Arakan. Notice.—Irrigation from wells in the North-Western Provinces and Oudh.

Vol. XVII, 1884.

Part 1.—Annual report for 1883. Considerations on the smooth-water anchorages or mud banks of Narrakal and Alleppy on the Travancore coast. Rough notes on Billa Surgam and other caves in the Kurnool district. On the geology of the Chuari and Sihunta parganas of Chamba. On the occurrence of the genus *Lyttonia*, Waagen, in the Kuling series of Kashmir.

Part 2.—Notes on the earthquake of 31st December 1881. On the microscopic structure of some Himalayan granites and gneissose granites. Report on the Choi coal exploration. On the re-discovery of certain localities for fossils in the Siwalik beds. On some of the mineral resources of the Andaman Islands in the neighbourhood of Port Blair. The intertrappean beds in the Deccan and the Laramie group in western North America.

Part 3.—On the microscopic structure of some Arvali rocks. Section along the Indus from the Peshawar Valley to the Salt-range. On the selection of sites for borings in the Raigarh-Hingir coal-field (first notice). Note on lignite near Raipore, Central Provinces. The Turquoise mines of Nishāpūr, Khorassan. Notice of a further fiery eruption from the Minbyin mud volcano of Cheduba Island, Arakan. Report on the Langrin coal-field, south-west Khasia Hills. Additional notes on the Umaria coal-field.

Part 4.—On the Geology of part of the Gangasulan pargana of British Garhwal. On fragments of slates and schists imbedded in the gneissose granite and granite of the North-west Himalayas. On the geology of the Takht-i-Suleiman. On the smooth-water anchorages of the Travancore coast. On auriferous sands of the Subansiri river, Pondicherry lignite, and phosphatic rocks at Musuri. Work at the Billa Surgam caves.

Vol. XVIII, 1885.

Part 1.—Annual report for 1884. On the country between the Singareni coal-field and the Kistna river. Geological sketch of the country between the Singareni coal-field and Hyderabad. On coal and limestone in the Doigrung river, near Golaghat, Assam. Homotaxis, as illustrated from Indian formations. Afghan field notes.

Part 2.—A fossiliferous series in the Lower Himalaya, Garhwal. On the probable age of the Mandhali series in the Lower Himalaya. On a second species of Siwalik camel (*Camelus Antiquus*, nobis ex Fale. and Caut. MS.). On the Geology of Chamba. On the probability of obtaining water by means of artesian wells in the plains of Upper India. Further considerations upon artesian sources in the plains of Upper India. On the geology of the Aka Hills. On the alleged tendency of the Arakan mud volcanoes to burst into eruption most frequently during the rains. Analyses of phosphatic nodules and rock from Mussooree.

Part 3.—On the Geology of the Andaman Islands. On a third species of *Merycopotamus*. Some observations on percolation as affected by current. Notice of the Pirthalla and Chandpur meteorites. Report on the oil-wells and coal in the Thayetmyo district, British Burma. On some antimony deposits in the Maulmain district. On the Kashmir earthquake of 30th May 1885. On the Bengal earthquake of 14th July 1885.

Part 4.—Geological work in the Chhattisgarh division of the Central Provinces. On the Bengal earthquake of July 14th 1885. On the Kashmir earthquake of 30th May 1885. On the results of Mr. H. B. Foote's further excavations in the Billa Surgam caves. On the mineral hitherto known as Nepaulite. Notice of the Sabetmahet meteorite.

Vol. XIX, 1886.

Part 1.—Annual report for 1885. On the International Geological Congress of Berlin. On some Palæozoic Fossils recently collected by Dr. H. Warth, in the Olive group of the Salt-range. On the correlation of the Indian and Australian coal-bearing beds. Afghan and Persian Field notes. On the section from Simla to Wangtu, and on the petrological character of the Amphibolites and Quartz Diorites of the Sutlej valley.

Part 2.—On the Geology of parts of Bellary and Anantapur districts. Geology of the Upper Dehing basin in the Singpho Hills. On the microscopic characters of some eruptive rocks from the Central Himalayas. Preliminary note on the Mammalia of the Karnul Caves. Memorandum on the prospects of finding coal in Western Rajputana. Note on the Olive group of the Salt-range. On the discussion regarding the boulder-beds of the Salt-range. On the Gondwana Homotaxis.

Part 3.—Geological sketch of the Vizagapatam district, Madras. Preliminary note on the geology of Northern Jesalmer. On the microscopic structure of some specimens of the Malani rocks of the Arvali region. On the Malanjkhadi copper-ore in the Balaghat district, C. P.

Part 4.—On the occurrence of petroleum in India. On the petroleum exploration at Khátan. Boring exploration in the Chhattisgarh coal-fields. Field-notes from Afghanistan: No. 3, Turkistan. Notice of a fiery eruption from one of the mud volcanoes of Cheduba Island, Arakan. Notice of the Nammianthal aerolite. Analysis of gold dust from the Meza valley, Upper Burma.

VOL. XX, 1887.

Part 1.—Annual report for 1886. Field-notes from Afghanistan: No. 4, from Turkistan to India. Physical geology of West British Garhwal; with notes on a route traverse through Jaunsar-Bawar and Tiri-Garhwal. On the geology of the Garo Hills. On some Indian image-stones. On soundings recently taken off Barren Island and Narcondam. On a character of the Talchir boulder-beds. Analysis of Phosphatic Nodules from the Salt-range, Punjab.

Part 2.—The fossil vertebrata of India. On the Echinoidea of the cretaceous series of the Lower Narbada Valley, with remarks upon their geological age. Field-notes: No. 5—to accompany a geological sketch map of Afghanistan and North-eastern Khorassan. On the microscopic structure of some specimens of the Rajmahal and Deccan traps. On the Dolerite of the Chor. On the identity of the Olive series in the east with the speckled sandstone in the west of the Salt-range in the Punjab.

Part 3.—The retirement of Mr. Medicott. Notice of J. B. Mushketoff's Geology of Russian Turkistan. Crystalline and metamorphic rocks of the Lower Himalaya, Garhwal, and Kumaun, Section I. Preliminary sketch of the geology of Simla and Jutogh. Note on the 'Lalitpur' meteorite.

Part 4.—Note on some points in Himalayan geology. Crystalline and metamorphic rocks of the Lower Himalaya, Garhwal, and Kumaun, Section II. The iron industry of the western portion of the District of Raipur. Notes on Upper Burma. Boring exploration in the Chhattisgarh coal-fields. (Second notice.) Some remarks on Pressure Metamorphism, with reference to the foliation of the Himalayan Gneissose Granite. A list and index of papers on Himalayan Geology and Microscopic Petrology, published in the preceding volumes of the records of the Geological Survey of India.

VOL. XXI, 1888.

Part 1.—Annual report for 1887. Crystalline and metamorphic rocks of the Lower Himalaya, Garhwal, and Kumaun, Section III. The Birds'-nest or Elephant Island, Mergui Archipelago. Memorandum on the results of an exploration of Jessalmer, with a view to the discovery of coal. A faceted pebble from the boulder bed ('speckled sandstone') of Mount Chel in the Salt-range in the Punjab. Examination of nodular stones obtained by trawling off Colombo.

Part 2.—Award of the Wollaston Gold Medal, Geological Society of London, 1888. The Dharwar System, the chief auriferous rock series in South India. On the Igneous rocks of the districts of Raipur and Balaghat, Central Provinces. On the Sangar Marg and Mehowgale coal-fields, Kashmir.

Part 3.—The Manganese Iron and Manganese Ores of Jabalpur. 'The Carboniferous Glacial Period.' The sequence and correlation of the pre-tertiary sedimentary formations of the Simla region of the Lower Himalayas.

Part 4.—On Indian fossil vertebrates. On the geology of the North-west Himalayas. On blown-sand rock sculpture. Re-discovery of Nummulites in Zanskar. On some mica traps from Barakar and Raniganj.

Vol. XXII, 1889.

- Part 1.*—Annual report for 1888. The Dharwar System, the chief auriferous rock-series in South India. (Second notice.) On the Wajra Karur diamonds, and on M. Chaper's alleged discovery of diamonds in pegmatite near that place. On the generic position of the so-called Plesiosaurus Indicus. On flexible sandstone or Itacolumite, with special reference to its nature and mode of occurrence in India, and the cause of its flexibility. On Siwalik and Narbada Chelonia.
- Part 2.*—Note on Indian Steatite. Distorted pebbles in the Siwalik conglomerate. 'The Carboniferous Glacial Period,' Notes on Dr. W. Waagen's 'Carboniferous Glacial Period.' On the oil-fields of Twingoung and Beme, Burma. The gypsum of the Nehal Nadi, Kumaun. On some of the materials for pottery obtainable in the neighbourhood of Jabalpur and of Umaria.
- Part 3.*—Abstract report on the coal outcrops in the Sharigh Valley, Baluchistan. On the discovery of Trilobites by Dr. H. Warth in the Neobolus beds of the Salt-range. Geological notes. On the Cherra Poonjee coal-field, in the Khasia Hills. On a Cobaltiferous Matt from Nepál. The President of the Geological Society of London on the International Geological Congress of 1888. Tin-mining in Mergui district.
- Part 4.*—On the land-tortoises of the Siwaliks. On the pelvis of a ruminant from the Siwaliks. Recent assays from the Sambhar Salt-Lake in Rajputana. The Manganiferous Iron and Manganese Ores of Jabalpur. On some Palagonite-bearing raps of the Ráj-mahál hills and Deccan. On tin-smelting in the Malay Peninsula. Provisional index of the local distribution of important minerals, miscellaneous minerals, gemstones, and quarry stones in the Indian Empire. *Part 1.*

Vol. XXIII, 1890.

- Part 1.*—Annual report for 1889. On the Lakadong coal-fields, Jaintia Hills. On the Pectoral and pelvic girdles and skull of the Indian Dicynodonts. On certain vertebrate remains from the Nagpur district (with description of a fish-skull). Crystalline and metamorphic rocks of the Lower Himalayas, Garhwál and Kumaun, Section IV. On the bivalves of the Olive-group, Salt-range. On the mud-banks of the Travancore coast.
- Part 2.*—On the most favourable sites for Petroleum explorations in the Harnai district, Baluchistan. The Sapphire Mines of Kashmir. The supposed Matrix of the Diamond at Wajra Karur, Madras. The Sonapet Gold-field. Field Notes from the Shan Hills, (Upper Burma). A description of some new species of Syringosphæridæ, with remarks upon their structures, &c.
- Part 3.*—On the Geology and Economic Resources of the Country adjoining the Sind-Pishin Railway between Sharigh and Spintangi, and of the country between it and Khattan (with a map). Report of a Journey through India in the winter of 1888-89, by Dr. Johannes Walther, translated from the German, by R. Bruce Foote. On the Coal-fields of Lairungao, Maosandram, and Mao-be-lar-kar, in the Khasi Hills (with 3 plans). Further Note on Indian Steatite. Provisional Index of the Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones, and Quarry Stones in the Indian Empire (continued from p. 286, Vol. XXII).
- Part 4.*—Geological sketch of Naini Tal; with some remarks on the natural conditions governing mountain slopes (with a map and plate). Notes on some Fossil Indian Bird Bones. The Darjiling Coal between the Lisu and the Ramthi rivers, explored during season 1890-91 (with a map). The Basic Eruptive Rocks of the Kadaph Area. The Deep Boring at Lucknow. Preliminary Note on the Coal Seam of the Dore Ravine, Hazara (with two plates).

Vol. XXIV, 1891.

- Part 1.*—Annual report for 1890. On the Geology of the Salt-range of the Punjab, with a re-considered theory of the Origin and Age of the Salt-Marl (with five plates). On veins of Graphite in decomposed Gneiss (Laterite) in Ceylon. Extracts from the Journal of a trip to the Glaciers of the Kabru, Pandim, &c. The Salts of the Sambhar Lake in Rajputana, and of the Saline efflorescence called 'Reh' from Aligarh in the North-Western Provinces. Analysis of Dolomite from the Salt-range, Punjab.
- Part 2.*—Preliminary Report on the Oil locality near Moghal Kot, in the Sheráni country, Suleiman Hills. On Mineral Oil from the Suleiman Hills. Note on the Geology of

the Lushai Hills. Report on the Coal-fields in the Northern Shan States. Note on the reported Namsèka Ruby-mine in the Mainglôn State. Note on the Tourmaline (Schorle) Mines in the Mainglôn State. Note on a Salt-spring near Bawgyo, Thibaw State.

Part 3.—Boring Exploration in the Daltongunj Coal-field, Palamow (with a map). Death of DR. P. MARTIN DUNCAN. Contributions to the study of the Pyroxenic varieties of Gneiss and of the Scapolite-bearing Rocks.

Part 4.—On a Collection of Mammalian Bones from Mongolia. Further note on the Darjiling Coal Exploration. Notes on the Geology and Mineral Resources of Sikkim (with a map). Chemical and Physical notes on rocks from the Salt-range, Punjab (with two plates).

VOL. XXV, 1892.

Part 1.—Annual report for 1891. Report on the Geology of Thal Chotiáli and part of the Mari country (with a map and 5 plates). Petrological Notes on the Boulder-bed of the Salt-range, Punjab, Sub-recent and Recent Deposits of the valley plains of Quetta, Pishin, and the Dasht-i-Bedaolat; with appendices on the Chamans of Quetta; and the Artesian water-supply of Quetta and Pishin (with one plate).

Part 2.—Geology of the Saféd Kôh (with 2 plates of sections). Report on a Survey of the Jherria Coal-field (with a map and 3 section plates) (out of print).

Part 3.—Note on the Locality of Indian Tscheffkinite. Geological Sketch of the country north of Bhamo. Preliminary Report on the economic resources of the Amber and Jade mines area in Upper Burma. Preliminary Report on the Iron-Ores and Iron-Industries of the Salem District. On the Occurrence of Riebeckite in India. Coal on the Great Tenasserim River, Mergui District, Lower Burma.

Part 4.—Report on the Oil Springs at Moghal Kot in the Shirani Hills (with 2 plates). Second Note on Mineral Oil from the Suleiman Hills. On a New Fossil, Amber-like Resin occurring in Burma. Preliminary notice on the Triassic Deposits of the Salt-range.

VOL. XXVI, 1893.

Part 1.—Annual report for 1892. Notes on the Central Himalayas (with map and plate). Note on the occurrence of Jadeite in Upper Burma (with a map). On the occurrence of Burmite, a new Fossil Resin from Upper Burma. Report on the Prospecting Operations, Mergui District, 1891-92.

Part 2.—Notes on the earthquake in Baluchistán on the 20th December 1892 (with 2 plates). Further Note on Burmite, a new amber-like fossil resin from Upper Burma. Note on the Alluvial deposits and Subterranean water-supply of Rangoon (with a map).

Part 3.—On the Geology of the Sherani Hills (with maps and plates). On Carboniferous Fossils from Tenasserim (with 1 plate). On a deep Boring at Chandernagore. Note on Granite in the districts of Tavoy and Mergui (with a plate).

Part 4.—On the Geology of the country between the Chappar Rift and Harnai in Baluchistán (with map and 3 plates). Notes on the Geology of a part of the Tenasserim Valley with special reference to the Tendau-Kamapying Coal-field (with two maps). On a Magnetite from the Madras Presidency containing Manganese and Alumina. On Hislopit (Haughton) (with a plate).

VOL. XXVII, 1894.

Part 1.—Annual report for 1893. Report on the Bhaganwala Coal-field, Salt-range, Punjab (with map and 2 plates).

Part 2.—Note on the Chemical qualities of petroleum from Burma. Note on the Singareni Coal-field, Hyderabad (Deccan) (with map and 3 plates of sections). Report on the Gohna Landslip, Garhwal (with 5 plates and 2 maps).

Part 3.—On the Cambrian Formation of the Eastern Salt-range (with a plate). The Girdih (Karharbari) Coal-field, with notes on the labour and methods of working (with 2 maps and 8 plates of sections). On the Occurrence of Chipped (?) Flints in the Upper Miocene of Burma (with a plate). Note on the Occurrence of Velates Schmideliana, Chemn., and Provelates grandis, Sow. Sp. in the Tertiary Formation of India and Burma (with 2 plates).

Part 4.—Note on the Geology of Wuntho in Upper Burma (with a map). Preliminary notice on the Echinoids from the Upper Cretaceous System of Baluchistán. On Highly Phosphatic Mica-Peridotites intrusive in the Lower Gondwana Rocks of Bengal. On a Mica-Hypersthene-Hornblende-Peridotite in Bengal.

Vol. XXVIII, 1895.

- Part 1.*—Annual report for 1894. *Cretaceous Formation of Pondicherry.* Some early allusions to Barren Island; with a few remarks thereon. Bibliography of Barren Island and Nandam, from 1884 to 1894; with some remarks.
- Part 2.*—On the importance of Cretaceous Rocks of Southern India in estimating the geographical conditions during later cretaceous times. Report on the Experimental Boring for Petroleum at Sukkur from October 1893 to March 1895. The development and Sub-division of the Tertiary system in Burma.
- Part 3.*—On the Jadeite and other rocks, from Tammaw in Upper Burma. On the Geology of the Tochi Valley. On the existence of Lower Gondwanas in Argentina.
- Part 4.*—On the Igneous Rocks of the Giridih (Kuhurbaree) Coal-field and their Contact Effects. On some outliers of the Vindhyan system south of the Sone and their relation to the so-called Lower Vindhyan. Notes on a portion of the Lower Vindhyan area of the Sone Valley. Note on DR. FRITZ NOETLING's paper on the Tertiary system in Burma, in the Records of the Geological Survey of India for 1895, Part 2.

Vol. XXIX, 1896.

- Part 1.*—Annual report for 1895. On the Acicular inclusions in Indian Garnets. On the Origin and Growth of Garnets and of their Micropegmatitic intergrowths in Pyroxenic rocks (with 1 plate).
- Part 2.*—Notes on the Ultra-basic rocks and derived minerals of the Chalk (Magnesite) hills, and other localities near Salem, Madras (with 2—6 plates). Preliminary notes on some Corundum localities in the Salem and Coimbatore districts, Madras (with 7—9 plates). On the occurrence of Corundum and Kyanite in the Manbhum district, Bengal. On the papers by DR. KOSSMAT and DR. KURTZ, and on the ancient Geography of "Gondwana-land." Notes from the Geological Survey of India.
- Part 3.*—On some Igneous Rocks from the Tochi Valley. Notes from the Geological Survey of India.
- Part 4.*—Report on the Steatite mines, Minbu District, Burma. Further notes on the Lower Vindhyan (Sub-Kaimur) area of the Sone Valley, Rewah. Notes from the Geological Survey of India.

Vol. XXX, 1897.

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- Part 3 (out of print).*—Mohpani coal-field. Lead-ore at Slimanabad, Jabalpur district. Coal east of Chhatisgarh between Bilaspur and Ranchi. Petroleum in Burma. Petroleum locality of Sudkal, near Futtijung, west of Rawalpindi. Argentiferous galena and copper in Manbhum. Assays of iron ores.
- Part 4 (out of print).*—Geology of Mount Tilla, Punjab. Copper deposits of Dalbhum and Singbhum: 1.—Copper mines of Singbhum: 2.—Copper of Dalbhum and Singbhum. Meteorites.

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- Part 2.*—Coasts of Baluchistan and Persia from Karachi to head of Persian Gulf, and some of Gulf Islands. Parts of Kummummet and Hanamconda districts in Nizam's Dominions. Geology of Orissa. New coal-field in south-eastern Hyderabad (Deccan) territory.
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- Part 2.*—Bisrampur coal-field. Mineralogical notes on gneiss of South Mirzapur and adjoining country.
- Part 3.*—Celt in ossiferous deposits of Narbada valley (Pliocene of Falconer): on age of deposits, and on associated shells. Barakars (coal-measures) in Beddadanoile field, Godavari district. Geology of parts of Upper Punjab. Coal in India. Salt-springs of Pegu.
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- Part 2 (out of print).*—Gold-fields of south-east Wynaad, Madras Presidency. Geological notes on Khareean hills in Upper Punjab. Water-bearing strata of Surat district. Geology of Scindia's territories.
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and Rhiptozamites, Schmalh., in palæozoic and secondary rocks of Europe, Asia, and Australia. Fossil plants from Kattywar, Shekh Budin, and Sirgulah. Volcanic foci of eruption in Konkan.

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- Part 2.**—Geology of parts of Bellary and Anantapur districts. Geology of Upper Dehing basin in Singpho Hills. Microscopic characters of eruptive rocks from Central Himalayas. Mammalia of Karnul Caves. Prospects of finding coal in Western Rajputana. Olive group of Salt-range. Boulder-beds of Salt-range. Gondwana Homotaxis.
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- Part 1.**—Annual report for 1886. Field-notes from Afghanistan: No. 4, from Turkistan to India. Physical geology of West British Garhwal; with notes on a route traversed through Jaunsar-Bawar and Tiri-Garhwal. Geology of Garo Hills. Indian image-stones. Soundings recently taken off Barren Island and Narcondam. Talchir boulder-beds. Analysis of Phosphatic Nodules from Salt-range, Punjab.
- Part 2.**—Fossil vertebrata of India. Echinoidea of cretaceous series of Lower Narbada Valley. Field-notes: No. 5—to accompany geological sketch map of Afghanistan and North-Eastern Khorassan. Microscopic structure of Rajmahal and Deccan traps. Dolerite of Chor. Identity of Olive series in east with speckled sandstone in west of Salt-range in Punjab.
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- Part 1.**—Annual report for 1887. Crystalline and metamorphic rocks of Lower Himalaya, Garhwal, and Kumaun, Section III. Birds'-nest or Elephant Island, Mergui Archipelago. Exploration of Jessalmer, with a view to discovery of coal. Facetted pebbles from boulder bed ('speckled sandstone') of Mount Chel in Salt-range, Punjab. Nodular stones obtained off Colombo.
- Part 2.**—Award of Wollaston Gold Medal, Geological Society of London, 1888. Dharwar System in South India. Igneous rocks of Raipur and Balaghat, Central Provinces. Sangar Marg and Mehowgale coal-fields, Kashmir.
- Part 3.**—Manganese Iron and Manganese Ores of Jabalpur. 'The Carboniferous Glacial Period.' Pre-tertiary sedimentary formations of Simla region of Lower Himalayas.
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- Part 1.**—Annual report for 1888. Dharwar System in South India. Wajra Karur diamonds, and M. Chaper's alleged discovery of diamonds in pegmatite. Generic position of so-called Plesiosaurus Indicus. Flexible sandstone or Itacolumite, its nature, mode of occurrence in India, and cause of its flexibility. Siwalik and Narbada Chelonia.
- Part 2.**—Indian Steatite. Distorted pebbles in Siwalik conglomerate. 'Carboniferous Glacial Period.' Oil-fields of Twingoung and Beme, Burma. Gypsum of Nehal Nadi, Kumaun. Materials for pottery in neighbourhood of Jabalpur and Umaria.
- Part 3.**—Coal outcrops in Sharigh Valley, Baluchistan. Trilobites in Neobolus beds of Salt-range. Geological notes. Cherra Poonjee coal-field, in Khasia Hills. Cobaltiferous Matt from Nepal. President of Geological Society of London on International Geological Congress of 1888. Tin-mining in Mergui district.
- Part 4.**—Land-tortoises of Siwaliks. Pelvis of a ruminant from Siwaliks. Assays from Sambhar Salt-Lake in Rajputana. Manganiferous iron and Manganese Ores of Jabalpur. Palagonite-bearing traps of Rájmahal hills and Deccan. Tin-smelting in Malay Peninsula. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones and Quarry Stones in Indian Empire. Part 1.

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- Part 1.*—Annual report for 1889. Lakadong coal-fields, Jaintia Hills. Pectoral and pelvic girdles and skull of Indian Dicynodonts. Vertebrate remains from Nagpur district (with description of fish-skull). Crystalline and metamorphic rocks of Lower Himalayas, Garhwál and Kumaun, Section IV. Bivalves of Olive-group, Salt-range. Mud-banks of Travancore coast.
- Part 2.*—Petroleum explorations in Harnai district, Baluchistan. Sapphire Mines of Kashmir. Supposed Matrix of Diamond at Wajra Karur, Madras. Sonapet Gold-field. Field-notes from Shan Hills (Upper Burma). New species of Syringosphæridæ.
- Part 3.*—Geology and Economic Resources of Country adjoining Sind-Pishin Railway between Sharigh and Spintangi, and of country between it and Khattan. Journey through India in 1888-89, by Dr. Johannes Walther. Coal-fields of Lairungao, Maosandram, and Mao-be-lar-kar, in the Khasi Hills. Indian Steatite. Provisional Index of Local Distribution of Important Minerals, Miscellaneous Minerals, Gem Stones, and Quarry Stones in Indian Empire.
- Part 4.*—Geological sketch of Naini Tal; with remarks on natural conditions governing mountain slopes. Fossil Indian Bird Bones. Darjiling Coal between Lisu and Ramthi rivers. Basic Eruptive Rocks of Kadapah Area. Deep Boring at Lucknow. Coal Seam of Dore Ravine, Hazara.

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- Part 1.*—Annual report for 1890. Geology of Salt-range of Punjab, with re-considered theory of Origin and Age of Salt-Mart. Graphite in decomposed Gneiss (Laterite) in Ceylon. Glaciers of Kabru, Pandim, etc. Salts of Sambhar Lake in Rajputana, and 'Reh' from Aligarh in North-Western Provinces. Analysis of Dolomite from Salt-range, Punjab.
- Part 2.*—Oil near Moghal Kot, in Sheráni country, Suleiman Hills. Mineral Oil from Suleiman Hills. Geology of Lushai Hills. Coal-fields in Northern Shan States. Reported Namsêka Ruby-mine in Mainglôn State. Tourmaline (Schorl) Mines in Mainglôn State. Salt-spring near Bawgyo, Thibaw State.
- Part 3.*—Boring in Daltongunj Coal-field, Palamow. Death of Dr. P. Martin Duncan. Pyroxenic varieties of Gneiss and Scapolite-bearing Rocks.
- Part 4.*—Mammalian Bones from Mongolia. Darjiling Coal Exploration. Geology and Mineral Resources of Sikkim. Rocks from the Salt-range, Punjab.

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- Part 1.*—Annual report for 1891. Geology of Thal Chotiáli and part of Mari country. Petrological Notes on Boulder-bed of Salt-range, Punjáb. Sub-recent and Recent Deposits of valley plains of Quetta, Pishin, and Dasht-i-Bedaolat; with appendices on Chamans of Quetta; and Artesian water-supply of Quetta and Pishin.
- Part 2 (out of print).*—Geology of Saféd Kôh. Jherria Coal-field.
- Part 3.*—Locality of Indian Tscheffkinite. Geological Sketch of country north of Bhamo. Economic resources of Amber and Jade mines area in Upper Burma. Iron-ores and Iron Industries of Salem District. Riebeckite in India. Coal on Great Tenasserim River, Lower Burma.
- Part 4.*—Oil Springs at Moghal Kot in Shirani Hills. Mineral Oil from Suleiman Hills. New Amber-like Resin in Burma. Triassic Deposits of Salt-range.

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- Part 1.*—Annual report for 1892. Central Himalayas. Jadeite in Upper Burma. Burmite, new Fossil Resin from Upper Burma. Prospecting Operations, Mergui District, 1891-92.
- Part 2.*—Earthquake in Baluchistán on 20th December 1892. Burmite, new amber-like fossil resin from Upper Burma. Alluvial deposits and Subterranean water-supply of Rangoon.
- Part 3.*—Geology of Sherani Hills. Carboniferous Fossils from Tenasserim. Boring at Chandernagore. Granite in Tavoy and Mergui.
- Part 4.*—Geology of country between Chappar Rift and Harnai in Baluchistán. Geology of part of Tenasserim Valley with special reference to Tendau-Kamapying Coal-field. Magnetite containing Manganese and Alumina. Hislopite.

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- Part 1.*—Annual report for 1893. Bhaganwala Coal-field, Salt-range, Punjab.
- Part 2.*—Petroleum from Burma. Singareni Coal-field, Hyderabad (Deccan). Gohna Landslip, Garhwál.

- Part 3.*—Cambrian Formation of Eastern Salt-range. Giridih (Karharbari) Coal-fields. Chipped (?) Flints in Upper Miocene of Burma. Velates Schmideliana, Chemn., and Provelates grandis. Sow. Sp., in Tertiary Formation of India and Burma.
- Part 4.*—Geology of Wuntho in Upper Burma. Echinoids from Upper Cretaceous System of Baluchistán. Highly Phosphatic Mica-Peridotites intrusive in Lower Gondwana Rocks of Bengal. Mica-Hypersthene-Hornblende-Peridotite in Bengal.

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- Part 1.*—Annual report for 1894. Cretaceous Formation of Pondicherry. Early allusion to Barren Island. Bibliography of Barren Island and Narcondam, from 1884 to 1894.
- Part 2.*—Cretaceous Rocks of Southern India and geographical conditions during later cretaceous times. Experimental Boring for Petroleum at Sukkur from October 1893 to March 1895. Tertiary system in Burma.
- Part 3.*—Jadeite and other rocks, from Tammaw in Upper Burma. Geology of Tochi Valley. Lower Gondwanas in Argentina.
- Part 4.*—Igneous Rocks of Giridih (Kurhurbaree) Coal-field and their Contact Effects. Vindhyan system south of Sone and their relation to so-called Lower Vindhyan. Lower Vindhyan area of Sone Valley. Tertiary system in Burma.

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